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ANALYSIS OF BROADCASTING SATELLITE SERVICE FEEDER LINK POWER CONTROL AND POLARIZATION

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BY

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SUMMARY

The use of Broadcasting-Satellite service (BSS) feeder links near 17 GHz may require very high transmitter power levels to overcome propagation losses that occur for only a small percentage of the time. Earth station power control could enable operation at much lower power levels most of the time and provide higher power only when necessary. Power control could be beneficial in terms of economics and reliability, but could conceivably lead to detrimental interference effects.

The United States is likely to receive more bandwidth or channels per service area per alloted orbit position at the 1983 Broadcasting-Satellite service planning conference (RARC-83) than can be utilized by a single satellite in a practical manner. This resource might nevertheless become fully utilized through the use of multiple satellites that are nominally co-located. A pertinent problem in this implementation scheme is the difference in the interference potential between feeder links using orthogonal linear and orthogonal circular polarizations.

The purpose of this study was to analyze BSS feeder link power control and polarization effects relating to the above mentioned problems. The objectives were to: 1) develop the analytical methods needed for the evaluation of these problems; 2) develop a precipitation attenuation and depolarization data base for use in the analyses; 3) perform a statistical analysis of carrier-to-interference power ratios (C/Is) for 0 dB, 5 dB, 10 dB,

15 dB and unlimited power control dynamic ranges; and 4) perform a detailed assessment of the relative advantages and disadvantages of linear and circular polarization for feeder links to nominally co-located satellites with overlapping coverage areas.

The analytical methods and data base were developed and documented in an Interim Report. CCIR methods for evaluating propagation factors and CCIR radiometeorological data were used to the greatest possible extent. The most significant finding of this effort was the discovery that precipitation scatter might be an influential interference mechanism at 17 GHz, but probably only in cases where the interference is neglegibly low.

The analysis of BSS feeder links using power control (Section II) showed that there are generally no detrimental interference effects from using power control. In a theoretical near-worst-case assessment, a feeder link having unlimited power control dynamic range was found to cause no more degradation due to interference than a fixed-EIRP link for percentages of time of interest, despite its radically higher short-term transmitter power levels. It was also shown that a feeder link using power control would suffer essentially no greater degradation from interference than a fixed-EIRP link having similar availability objectives. Feeder links using various power control dynamic ranges were examined in a representative BSS orbit position allotment plan. It was found that the previous theoretical results with regard to interference were valid for this scenario. In addition, it was shown that the baseline transmitter power (power control not activated) which is the required long-term value (for upwards of 95% of the worst-month) is significantly lower than the power needed in a fixed-EIRP link.

The analysis of feeder link polarization (Section III) showed that the use of ideal orthogonal linear rather than circular polarizations results in no C/I performance improvement during rain for the case of victim and interfering links that have uncorrelated rain conditions. This corresponds with feeder links whose earth stations are separated by more than the rain-correlation distance. However, when the earth stations are separated by

less than this distance, some improvement in C/Is during rain was found to be possible through the use of orthogonal linear rather than circular polarizations. This improvement exceeded a few tenths of a dB only under the following conditions:

- The earth stations in the victim and interfering links are nominally co-located; and

- The earth stations are located in a relatively wet climate (e.g., rain zones K, M, P); and

- The antenna elevation angles are low (e.g., 20^{0}) so as to enable significant cross-polarization reductions due to rain.

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I. INTRODUCTION

BACKGROUND

The 1983 Regional Administrative Radio Conference (RARC-83) will establish a Region 2 plan for the 12 GHz Broadcasting-Satellite service (BSS) and associated 17 GHz feeder links. Region 2 essentially consists of North, Central, and South America and certain territories in the Atlantic and Pacific oceans. Considerable attention has been given to the 12 GHz downlinks; however, the 17 GHz feeder links have been studied to a lesser extent.

The feeder link carrier power level at a BSS space station is dependent on radiometeorological conditions, link geometry, and the earth station EIRP. For example, the received carrier power level will generally decrease with increasing rain rates when all other factors remain constant. Similarly, interference levels at a BSS space station are affected by these factors on the interference paths. One prospective means for combating decreases in the wanted carrier power level that could affect the RARC-83 planning and post-RARC BSS implementation is feeder link power control.

Power control enables increases in earth station EIRP so as to compensate for short-term increases in propagation loss. The desired effect is to maintain the wanted feeder link carrier power level above a minimum required level for all but an acceptably small percentage of time. This approach to fulfilling feeder link availability requirements is an alternative

to the common practice of utilizing a constant EIRP that includes a margin for short-term propagation losses. Thus, power control might provide the minimum required EIRP at all times as opposed to the excessively high EIRP that would be used in the typical constant-EIRP earth station during normally-present propagation conditions. The CCIR Special Preparatory Meeting (SPM) for WARC-79 endorsed the use of power control as a means for achieving optimum use of the spectrum: "Whenever possible, power outputs should be adjustable to match propagation conditions."[1] However, the achievement of higher availabilities through power control could be accompanied by increased levels of interference power in other BSS space stations and other detrimental effects.

Interference at BSS space stations is affected not only by the magnitude of interfering emissions at the spacecraft antenna, but also the polarization. Polarization discrimination of BSS space stations against interfering emissions can be used to provide isolation between satellite networks. However, the polarization discrimination is a random variable that depends on the type of polarization used, (linear or circular), and radiometeorological and geometric factors. A problem of particular concern to the U.S. is the choice of polarization for feeder links to co-located satellites with overlapping service areas. A particular choice of polarization type may be preferred if feeder link polarization isolation is to be used in establishing frequency/orbit allotments at RARC-83 or for post RARC-83 implementation.

This report presents the analytical methods (Appendix A) and data base (Appendix D) for use in the study of power control and polarization, as well as specific results from applications of the data base and analysis methods to prospective Region 2 BSS feeder links using various power control and polarization implementations.

OBJECTIVES

The objectives of this study were to:

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[1]CCIR, "Technical Aspects of Optimum Use of the Spectrum," Chapter 7, SPM Report, Geneva, Switzerland, November 1978.

- Develop the analytical methods to evaluate feeder link polarization and power control.

- Develop a data base for precipitation attenuation and depolarization for 12 GHz and 17.5 GHz.

- Perform a detailed statistical analysis of co-channel and adjacent channel carrier-to-interference power ratios for the cases of 0 dB, 5 dB, 10 dB, 15 dB and unlimited maximum levels of power control.

- Perform a detailed assessment of the relative advantages and disadvantages of linear and cirular polarization in feeder links to nominally co-located satellites.

APPROACH

The overall study was divided into two parts. The first part was the development of the analytical methods and data base, the results of which were documented in an interim report[2]. The second part was the statistical analysis of carrier-to-interference power ratios for various power control conditions and feeder link scenarios as well as the assessment of the relative advantages and disadvantages of linear and circular polarization. The results of both parts are documented in this final report.

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[2] Sullivan, T.M., Analysis of Broadcasting-Satellite Feeder Link Power Control and Polarization (Analysis Methods and Data Base), ORI Technical Memorandum No. 127-82, 26 May 1982.

II. POWER CONTROL ANALYSIS RESULTS

INTRODUCTION

Factors involved in uplink power control implementation and the methodology for evaluating power control interference effects are presented in Appendix A. The approach in Appendix A is used in this section in the performance of a theoretical assessment and hypothetical-case study of the interference effects of feeder link power control. First, it is shown that the use of power control will not necessarily increase the probability of unacceptable interference in the context of post-WARC-83 BSS system implementation. A representative Region 2 BSS allotment scenario is then examined to determine the statistical interference effects of various power control implementations. Conclusions are given in Section IV.

THEORETICAL ASSESSMENT OF POWER CONTROL

The orbit/frequency allotment plan to be developed at WARC-83 may specify various feeder link parameters such as polarization. The plan will ensure that there will not be unacceptable interference if all provisions of the plan are observed. Power control in a feeder link earth station could represent a significant deviation from the plan since feeder link power control is not likely to be considered as a planning element. Instead, fixed feeder link EIRPs are expected to be considered in the calculation of carrier-

to-interference power ratios when prospective orbit/frequency allotment plans are considered.[1] These EIRPs will enable the fulfillment of availability objectives while limiting the interference between feeder links.

Interference to a Feeder Link Using Power Control

An example statistical variation of C/Is that result when the desired signal is transmitted from an earth station using power control is illustrated in Figure 2.1, wherein it is assumed that a C/N of 26 dB and protection ratio (PR) of 40 dB must be exceeded for 99 percent of the worst-month. The fixed-EIRP feeder link C/I is greater than 40 dB and the C/N is greater than 26 dB for time percentages less than 99. This is due to the fact that the fixed-EIRP is higher than necessary for all but one percent of the worst-month. Power control may be used to enable a reduction in EIRP except when higher EIRPs are needed to overcome short-term attenuation. For example, a power control system could be designed to enable operation at a relatively low baseline EIRP for most of the time (e.g., 90 percent of the worst-month) and provide higher EIRPs only when necessary. Figure 2.1 (dashed-curve) shows example resultant C/Ns and C/Is for such a system. Note that the PR is exceeded for all but the acceptable one percent of the worst-month.

The following equations can be used to substantiate the fact that a BSS feeder link using power control will not suffer unacceptable degradation.

$$PR \leq \frac{C}{I}(p) = C(p) \div \sum I(10) \ , \qquad \text{for } p \leq p' \tag{1}$$

$$C(p) = P_t \times G_t \times G_r \div L_{fs} \div L_r(p) \geq \frac{C(p')}{N} \times N, \ p \leq p' \tag{2}$$

where

PR = protection ratio (numerical) to be exceeded for p' percent of the worst-month;

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[1] CCIR, Technical Bases for the Regional Administrative Radio Conference 1983 for the Planning of the Broadcasting-Satellite Service in Region 2, Geneva, Switzerland, 1982.

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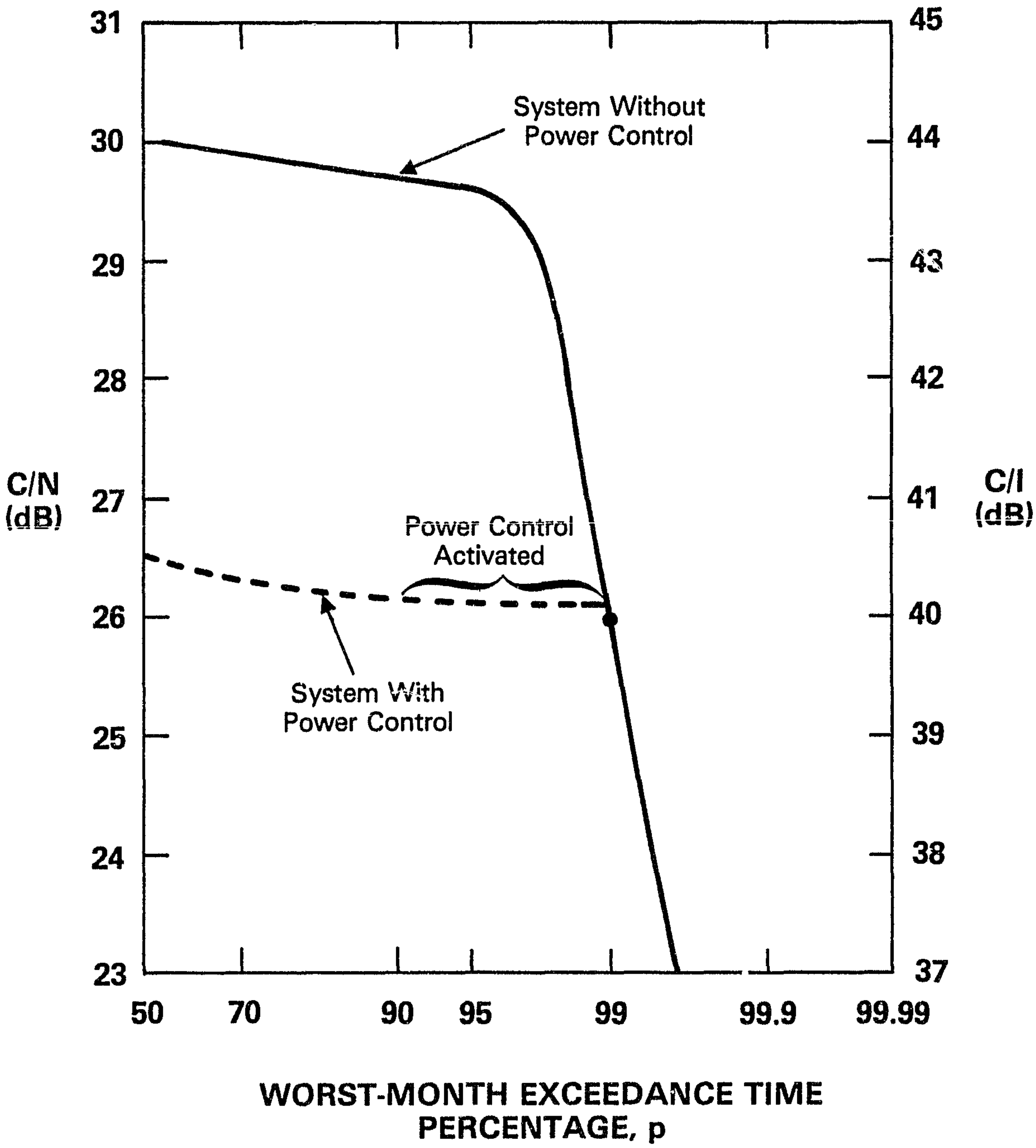

FIGURE 2.1. HYPOTHETICAL CUMULATIVE DISTRIBUTIONS OF C/N and C/I IN FEEDER LINKS USING FIXED-EIRP AND POWER CONTROL

$\frac{C}{I}(p)$ = carrier-to-interference power ratio (numerical) exceeded for p percent of the worst-month

$C(p)$ = received carrier power level exceeded for p percent of the worst-month (watts);

$I(10)$ = total feeder link interference power (watts) where the power level of each entry is that which is exceeded for no more than 10% of the worst-month;

P_t = transmitter power (watts) input to the earth station antenna in the desired link;

G_t, G_r = main beam gains (numerical power ratios) of the earth and space station antennas;

L_{fs} = free space loss (numerical power ratio);

$L_r(p)$ = rain attenuation (numerical power ratio) exceeded for no more than p % of the worst-month;

$\frac{C(p')}{N}$ = carrier-to-noise power ratio (numerical) to be exceeded for p'% of the worst-month, where p' is the availability objective;

N = maximum satellite receiver effective noise power (watts).

Equation 1 is the criterion for acceptable feeder link interference. This results from the fact that feeder link C/I is dependent only on desired signal attenuation - interference will not increase significantly above I(10) provided that power control is not used on an interfering feeder link. (Power control on an interfering link is addressed later). Thus, C(p) must be greater than or equal to C(p') as shown in Equation 2, when $p < p'$, in order for the PR availability criteria to be met.

Equation 2 is the criterion for selecting the minimum feeder link transmitter power P_t that will fulfill the PR and C/N availability objectives. When C(p) = C(p'), P_t is the minimum required transmitter power for a fixed-EIRP (no power control) feeder link. When $p < p'$, values for $L_r(p)$ will be less than $L_r(p')$ and lower values of P_t could be used while still meeting the Equation 2 criteria. This is essentially what occurs with power control, where P_t is reduced by as much as $L(p') - L(p)$ when $p < p'$. It can be seen in Equation 2 that values for C(p) when power control is used can be lower than those when power control is not used, except when $p = p'$. The power control system of Appendix A would result in essentially a constant C(p) for $p < p'$. Consequently, C/I (p) in Equation 1 would also remain essentially constant for $p \leq p'$ when power control is used on the desired feeder link. However, this constant C/I fulfills the criteria of Equation 1 as can be seen in Figure 2.1. Thus, the use of power control in a feeder link does not increase the probability of unacceptable interference to that link as compared to that of a fixed-EIRP feeder link meeting the criteria in Equations 1 and 2.

<u>Interference From a Feeder Link Using Power Control</u>

Power control could result in greater interference than that from a fixed-EIRP feeder link if and only if its maximum transmitter power exceeds that of the fixed-EIRP link. If the maximum power of the interfering earth station using power control is equal to that of fixed-EIRP earth stations, Equation 1 would predict a lower bound on the C/I for any p, where $p \leq p'$. The actual C/I due to interference from such a power-controlled earth station would be higher than that caused by the fixed-EIRP earth stations for all p. This results from the following: 1) the interfering power-controlled earth station's power never exceeds that of the fixed-EIRP interfering earth stations, and 2) the probability of a simultaneous fade of the desired signal C and an increase in the power-controlled earth station's power is small. On the other hand, what is the effect on victim C/Is when the power-controlled interferer's dynamic range is not limited as in this case? This is considered next.

Figure 2.2 illustrates a geometry where interference from a power-controlled earth station during rain could exceed that during clear-sky. A near worst-case geometry for interference from a power-controlled feeder link with unlimited dynamic range would be: 1) the interference path elevation angle is 90° and 2) the desired signal path elevation angle of the interferer is 20° (approximately the lowest tolerable angle in moderate- to heavy-rain climates. Other parameters that would emphasize the feeder link interference (in terms of C/I) would be:

- Interfering earth station rain climate = P (see Appendix D).
- Desired signal C comes from an earth station in a light-rain climate (e.g., Canada).

For the above near worst-case scenario, C/Is for the cases of interfering feeder links with 1) fixed-EIRP and 2) power control of unlimited dynamic range have been calculated and plotted in Figure 2.3. Also plotted are the interfering earth station power levels for both cases. The following parameters were assumed for the victim and interfering feeder links and the interference path.

- Earth Station Mainbeam Gain = 56.5 dBi
- Victim Satellite Mainbeam Gain = 34.1 dBi
- Interfering Feeder Link Satellite Mainbeam Gain = 35.5 dBi
- Victim Service Area Rain Zone = K (Northeast Canada)
- Interferer's Service Area Rain Zone = P (Brazil)
- Interfering Feeder Link Earth Station at 0° Latitude, 85°W Longitude and Satellite at 147°W Longitude
- Victim Feeder Link Earth Station at 45.4°N Latitude, 74°W Longitude and Satellite at 85°W Longitude

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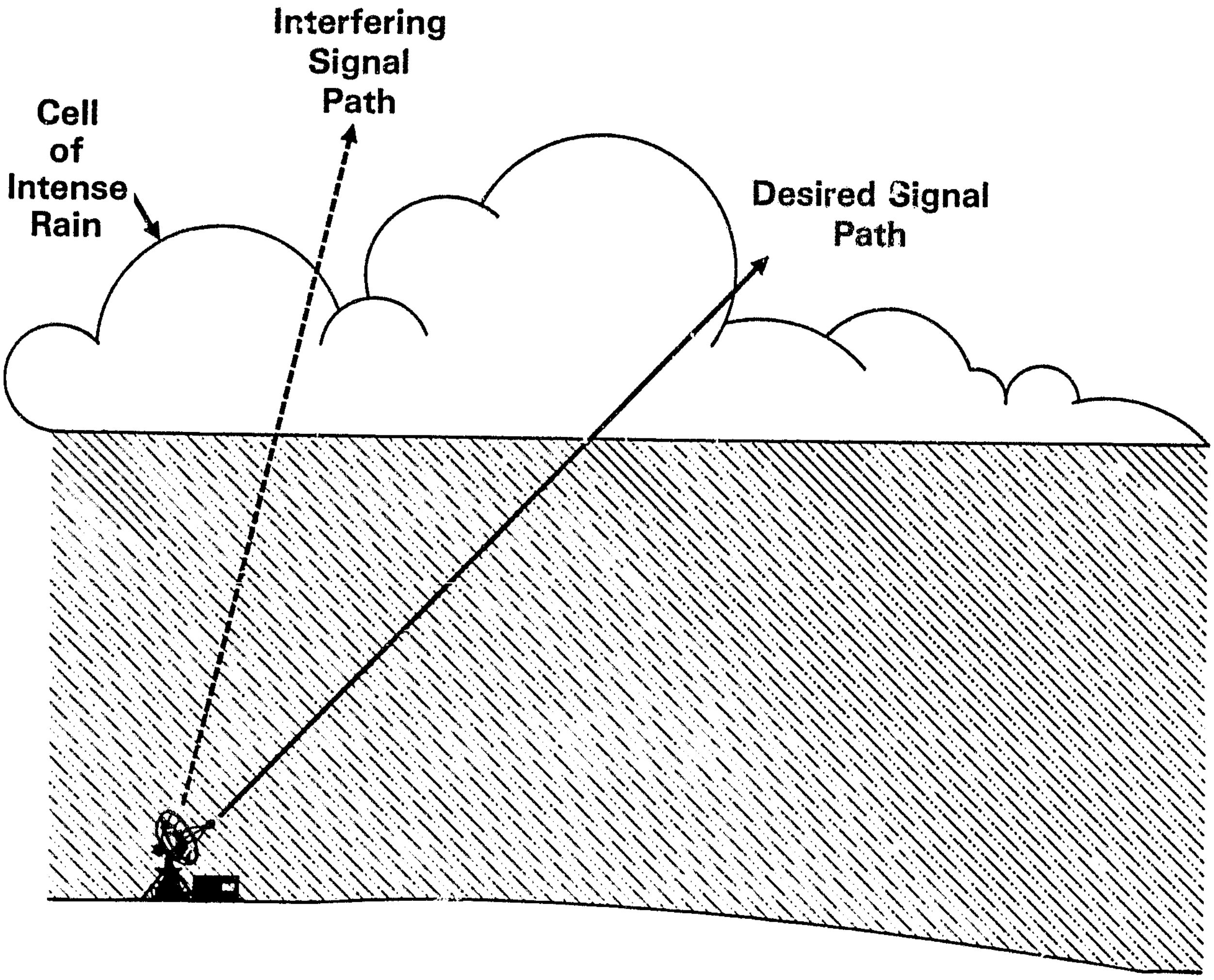

FIGURE 2.2 ILLUSTRATION OF GEOMETRY WHERE INTERFERENCE FROM AN EARTH STATION WITH POWER CONTROL MIGHT INCREASE WHILE ITS DESIRED SIGNAL AT THE SATELLITE REMAINS CONSTANT
(Interfering Signal Path has a Higher Elevation Angle than the Desired Signal Path)

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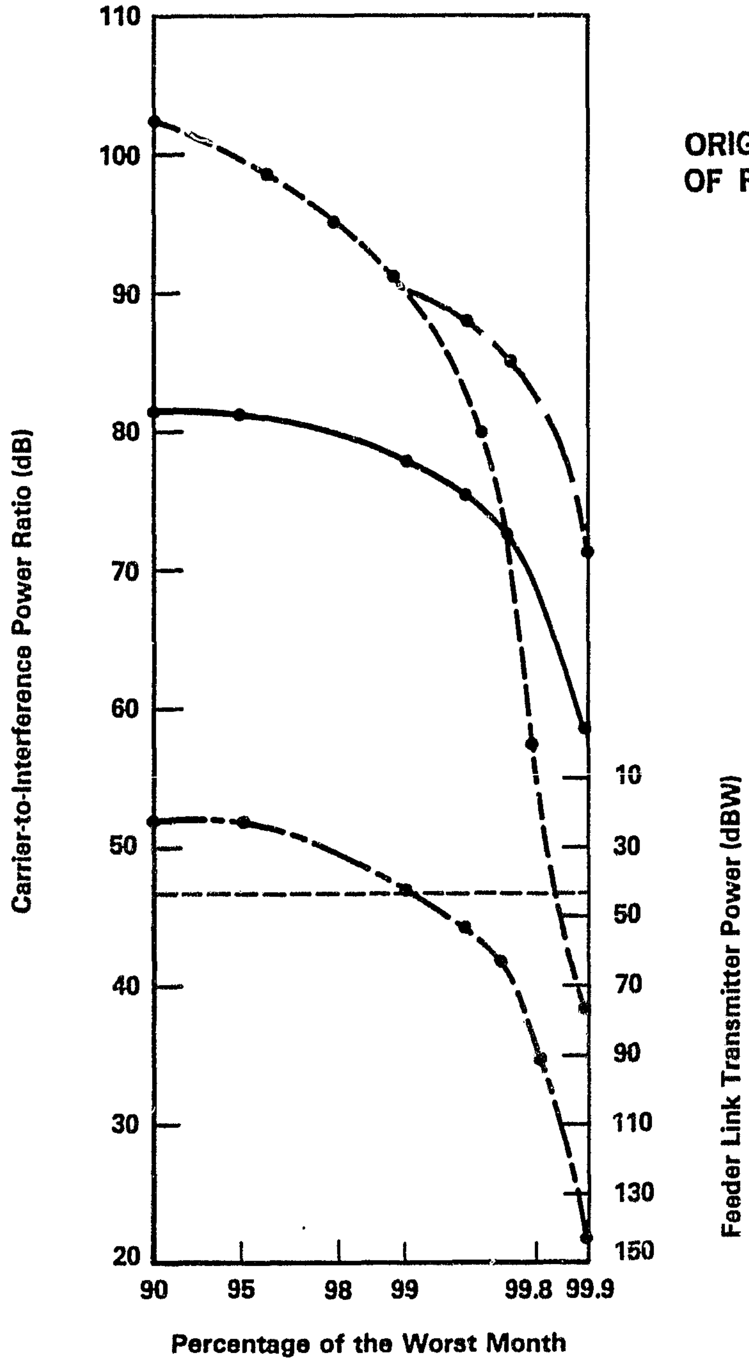

——— = Fixed — EIRP Feeder Link C/I
– – – – = Power — Controlled Feeder Link C/I (Unlimited Dynamic Range)
— — = Power — Controlled Feeder Link C/I (Max. Power = That of the Fixed — EIRP Link)
- - - - - = Fixed — EIRP Feeder Link Transmitter Power
— - — = Power — Controlled Feeder Link Transmitter Power

FIGURE 2.3. NEAR WORST-CASE COMPARISON OF FIXED-EIRP AND POWER-CONTROLLED FEEDER LINKS

- Interfering Feeder Link Elevation Angle = 20^0

- Victim Feeder Link Elevation Angle = 36.6^0

- Interference Path Elevation Angle = 90^0

- Carrier (Desired Signal) Power Level Required at Satellite Antenna Output, to be Exceeded for 99% of the Worst-Month, is -95.3 dBW

It can be seen in Figure 2.3 that the transmitter power of the interferer must be about 43.7 dBW in order for its feeder link to provide a desired signal of at least -95.3 dBW for 99% of the worst-month. When this interferer is power-controlled, it must provide the same power during the rain conditions associated with 99% of the worst-month. The interference power from the fixed-EIRP earth station will not increase significantly above the mean clear-sky level, (only water vapor attenuation reductions would cause clear sky variability); thus, the C/I at the victim for large exceedance time percentages is based only on desired signal variability (Equation 6 of Appendix A). However, in the case of the power-controlled interferer, the interference increases during rain at the interferer's site. This is because power control is increasing power in response to attenuations on the interferer's desired signal path that exceed the concomitant attenuations on the interference path. Thus, the independent increases in interference and decreases in desired signal power levels at the victim must be taken into account in determining the C/I at the victim (Equation 5 of Appendix A).

Figure 2.3 clearly shows that in this near-worst-case scenario for interference from a power-controlled earth station, the degradation caused by the power-controlled earth station is considerably less than that caused by a comparable fixed-EIRP earth station for the time percentages of interest. These degradations become similar at 0.3 percent of the worst-month and the power-controlled earth station of unlimited dynamic range produces greater degradation for less than 0.3 percent of the worst-month. Recall that the availability objective was 1.0% of the worst-month, which indicates that interference from an earth station of unlimited power control dynamic range is

much more acceptable than that of a fixed-EIRP earth station. Further examination of Figure 2.3 shows that if the power control dynamic range is limited so that the power cannot exceed about 62.5 dBW, (18.8 dB more than the fixed-EIRP interferer's power), the degradation will never be worse than that from the fixed-EIRP earth station.

Clearly, the degradation caused by an earth station using power control is no worse than that from a comparable fixed-EIRP earth station.

HYPOTHETICAL-CASE STUDY

The BSS feeder links described in Table 2.1 were selected for examination of the statistical variation of C/Is for various power control implementations. These links provide a cross section of Region 2 feeder link earth station rain zone sites. The power control system parameters were selected to provide the same C/N for a 99 percent worst-month exceedance time percentage as a fixed-EIRP feeder link (i.e., OdB power control dynamic range), as explained in Appendix A. Table 2.2 shows the statistical desired signal levels at the satellite and the baseline earth station power levels (power control not activated) for each link. The resulting C/Is are shown in Tables 2.3 through 2.26 (at the end of the section). Interference to and from feeder links using power control is considered. These two cases establish bounds for the situation where the desired and interfering emissions both emanate from earth stations using power control. It should be noted that the Appendix B approach for determining equivalent gain can give higher gains on cross-polarized interference paths than for the co-polar case. This effect, which can result in lower cross-polar C/Is than those for the co-polar sharing case (e.g., Table 2.9), is due to the conservative calculation of equivalent gain with respect to interference (see Appendix B).

The relative magnitudes of the C/Is are of particular interest in comparing cases of OdB, 5dB, 10dB, 15dB and unlimited power control dynamic ranges. These are assessed below in the following categories:

- Influence of climate on power control effects.

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TABLE 2.1

FEEDER LINK PARAMETERS

SERVICE AREA	SATELLITE LONGITUDE (degrees)	EARTH STATION PARAMETERS			RAIN CLIMATE ZONE
		LATITUDE (degrees)	LONGITUDE (degrees)	ANT. ELEV. ANGLE (degrees)	
Western Canada (C1P)	143 W	49.3 N	123.1 W	30.3	B
Alaska (ALS)	170 W	62.3 N	152.9 W	18.1	C
Hawaii (HWA)	170 W	21.3 N	160.4 W	62.5	D
West-Central Canada (C2P)	143 W	53.6 N	113.5 W	23.1	E
Chile/Argentina (CHA)	75 W	31.2 S	65.5 W	52.2	F
Greenland (GRL)	61 W	65.3 N	39.1 W	14.5	G
Northeast Canada (C5P)	85 W	45.4 N	74.0 W	36.6	K
Northern Mexico (MXN)	120 W	19.5 N	99.0 W	56.9	M
Brazil (BBB)	90 W	16.0 S	47.5 W	38.3	N
Guyana/Surinam (GUS)	62 W	4.8 N	56.8 W	81.7	P

TABLE 2.2

FEEDER LINK
TRANSMITTER AND RECEIVER CARRIER POWER LEVELS
WITH VARIOUS POWER CONTROL DYNAMIC RANGES

Service Area	Power Control Dynamic Range (dB)	Baseline Trans. Power Level (dBW)	Received Carrier Power (dBW) Worst-Month Exceedance Time Percentage				
			90	95	99	99.5	99.9
C1P	0	21.9	-94.4	-94.4	-95.3	-95.8	-100.1
	5	21.0	-95.3	-95.3	"	-95.3	-96.0
	10	"	"	"	"	"	95.3
	15	"	"	"	"	"	"
	Unlimited	"	"	"	"	"	"
ALS	0	22.8	-94.2	-94.2	-95.3	-96.0	-101.6
	5	21.7	-95.3	-95.3	"	-95.3	-97.7
	10	"	"	"	"	"	95.3
	15	"	"	"	"	"	"
	Unlimited	"	"	"	"	"	"
HWA	0	19.9	-94.5	-94.5	-95.3	-95.8	-100.3
	5	19.1	-95.3	-95.3	"	-95.3	-96.1
	10	"	"	"	"	"	-95.3
	15	"	"	"	"	"	"
	Unlimited	"	"	"	"	"	"
C2P	0	19.6	-93.3	-93.3	-95.3	-96.4	-105.6
	5	17.6	-95.3	-95.3	"	-95.3	-102.6
	10	"	"	"	"	"	-97.6
	15	"	"	"	"	"	-95.3
	Unlimited	"	"	"	"	"	"
CHA	0	27.8	-93.4	-93.4	-95.3	-96.4	-105.1
	5	25.9	-95.3	-95.3	"	-95.3	-102.0
	10	"	"	"	"	"	-97.0
	15	"	"	"	"	"	-95.3
	Unlimited	"	"	"	"	"	"

TABLE 2.2 (Cont.)

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Service Area	Power Control Dynamic Range (dB)	Baseline Trans. Power Level (dBW)	Received Carrier Power (dBW) Worst-Month Exceedance Time Percentage 90	95	99	99.5	99.9
GRL	0	20.9	-92.4	-92.4	-95.3	-96.9	-109.9
	5	18.0	-95.3	-95.3	"	-95.3	-107.8
	10	"	"	"	"	"	-102.8
	15	"	"	"	"	"	-97.8
	Unlimited	"	"	"	"	"	-95.3
C5P	0	26.9	-91.5	-91.5	-95.3	-97.3	-113.5
	5	23.1	-95.3	-95.3	"	-96.1	-112.3
	10	"	"	"	"	-95.3	-107.3
	15	"	"	"	"	"	-102.3
	Unlimited	"	"	"	"	"	-95.3
MXN	0	27.6	-91.4	-91.4	-95.3	-97.3	-114.4
	5	23.7	-95.3	-95.3	"	-96.2	-113.3
	10	"	"	"	"	-95.3	-108.3
	15	"	"	"	"	"	-103.3
	Unlimited	"	"	"	"	"	-95.3
BBB	0	37.4	-87.2	-87.3	-95.3	-99.4	-133.9
	5	32.4	-92.2	-92.3	"	-99.4	-133.9
	10	29.3	-95.3	-95.3	"	-97.5	-132.0
	15	"	"	"	"	-95.3	-127.0
	Unlimited	"	"	"	"	"	-95.3
GUS	0	27.9	-85.5	-85.6	-95.3	-100.2	-141.1
	5	22.9	-90.5	-90.6	"	-100.2	-141.1
	10	18.1	-95.3	-95.3	"	-100.0	-140.9
	15	"	"	"	"	-95.3	-135.9
	Unlimited	"	"	"	"	"	-95.3

- Influence of link geometry on power control effects.

- Effects of power control dynamic range.

Influence of Climate on Power Control Effects

The rain attenuation associated with a given exceedance time percentage generally increases as the rain climatic zone is varied from CCIR zone A (relatively light rain) through zone P (relatively heavy rain). The rain rates (and attenuations) increase more rapidly with decreasing exceedance time percentages as the rain climatic zone is varied from A to P as can be seen in Appendix D. Thus, a given power control dynamic range can more readily increase the feeder link availability in the lighter-rain zones (e.g., zone B). This effect is evident in Table 2.2, wherein statistical received carrier power levels are tabulated for various power control dynamic ranges. The availability objective is assumed to be a received carrier power level of -95.3 dBW exceeded for 99 percent of the worst-month (C(99) = -95.3 dBW). The Table 2.2 carrier power levels for the C1P service area (zone A) show that a power control dynamic range of 5 dB is sufficient to increase the availability from 99 percent to almost 99.9 percent of the worst-month. However, this same dynamic range extends the availability from C5P (zone K) to less than 99.5 percent and results in no availability increase for BBB, even though these sites provide slightly higher slant path elevation angles.

The climate is very influential on the statistical distribution of C/Is for a given power control dynamic range at the victim or interfering earth station. When the victim uses power control, the exceedance time percentage of a C/I threshold is more readily increased in the lighter-rain zones with a given power control dynamic range. Again, using C1P, C5P and BBB as examples, Tables 2.4, 2.12 and 2.14 show this effect. A 5 DB dynamic range is sufficient to extend the C1P exceedance time percentage of C/I(99) to at least 99.9 percent (availability), but to only lesser availabilities at C5P and BBB. On the other hand, the time during which the feeder link operates near the C/I(99) threshold is increased. This results from the method used to determine the power control system parameters (Appendix A), where the lowest possible power is always used and power control provides dB for dB attenuation

compensation. This is effectively a worst-case approach in terms of long-term C/Is - lesser power reductions from the 99% of the time value would of course yield higher long-term C/Is.

When an interferer uses power control, the C/I improvement is higher with relatively heavier-rain zones at the interferer's earth station site. This can be seen in the odd numbered tables (2.3, 2.5, etc.), wherein a given power control dynamic range results in higher C/I improvements for heavier-rain zones. This results from the elatively low required EIRPs during clear-sky (e.g., $p < 97$ percent) in heavy-rain zones as compared to that needed during rain (e.g., $p \geq 97$ percent).

Influence of Geometry on Power Control Effects

The desired signal path elevation angle as well as those for interference paths have a significant effect on the C/I caused by feeder links using power control. An interferer using power control could conceivably cause greater interference during rain than during clear-sky conditions. When an earth station's interference path elevation angle is higher than that of its desired signal path, the interference it causes could increase even though its desired signal power at the intended receiver remains constant due to the power control compensation for attenuation, as was discussed in the earlier theoretical assessment. This geometry was encountered in the cases in Tables 2.5/6, 2.9/10, 2.11/12, 2.15/16 and 2.19/20. When the interferer using power control was located in a heavy-rain zone (Tables 2.11/12, 2.15/16, and 2.17/18), there was in fact a small increase ($<$2dB) in interference during rain (at the interfer's site) over that which was present during clear sky conditions. These small interference increases had virtually no effect on the statistical C/I, because in all cases the desired signal variation predominated in the C/I statistics (Equation A-6).

Effects of Power Control Dynamic Range

The power control dynamic range strongly affects the exceedance time percentages associated with a given C/N or C/I threshold. In Table 2.2, the required carrier power level is exceeded for almost 99.9 percent of the time

with a 5 dB dynamic range in the C1P and ALS links (zones B and C), whereas 10 dB is needed for about the same performance in the HWA, C2P, CHA, GRL and C5P links (zones D, E, F, G and K). In all cases, the C/N availability has been significantly increased beyond 99 percent, but only through the short-term use of EIRPs that are greater than that which yields 99 percent availability without power control.

In the cases of BBB and GUS in Table 2.2 (rain zones N and P), a 5 dB power control dynamic range was insufficient to compensate for the variation in attenuation between 90 percent and 99 percent of the worst-month. That is, the baseline EIRP (power control deactivated) was higher than necessary most of the time (i.e., during clear sky or light rain) to enable the 99 percent availability to be met with a power control dynamic range of only 5 dB. However, the C/I improves at p 99 when one of these earth stations with 5 dB dynamic range was the interferer (Tables 2.1, 2.5, and 2.9). When these earth stations were in the victim feeder link, the feeder link operated near its C/I(99) value and C/N threshold (-95.3 dBW carrier in Table 2.2) for less time as compared to the case where the power control dynamic range in these links was greater.

SUMMARY OF POWER CONTROL EFFECTS

In comparison with a fixed-EIRP feeder link, power control can enable satisfactory operation with reduced transmitter power levels for upwards of 95% of the time while enabling the fulfillment of availability objectives through short-term power boosts. As a victim of interference, a power-controlled link operates with lower long-term C/I (and C/N) if such power reductions are used, but these long-term C/Is (and C/Ns) are established by the power control system design (e.g., baseline power level). As an interferer, the power controlled feeder link enables higher victim C/Is for the time percentages of concern, as compared with a fixed-EIRP interferer, even when the power control dynamic range is unlimited. These results pertain to the case where the victim and interfering feeder links have uncorrelated rain conditions, as would occur when their respective earth stations are well separated in distance (e.g., separated by 20 km).

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TABLE 2.3

SINGLE ENTRY C/Is - INTERFERENCE FROM ALS
(WITH POWER CONTROL) TO C1P (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	78.7	78.7	77.8	77.3	73.0	81.2	81.2	80.3	79.8	75.5
5	79.8	79.8	78.9	78.4	74.1	82.3	82.3	81.4	80.9	76.6
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.4

SINGLE ENTRY C/Is - INTERFERENCE FROM ALS
(WITH FIXED-EIRP)* TO C1P (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	78.7	78.7	77.8	77.3	73.0	81.2	81.2	80.3	79.8	75.5
5	77.8	77.8	"	77.8	77.1	80.3	80.3	"	80.3	79.6
10	"	"	"	"	77.8	"	"	"	"	80.3
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 30.3°;
the interfering signal path elevation angle is 19.0°.

TABLE 2.5

SINGLE ENTRY C/Is - INTERFERENCE FROM C1P
(WITH POWER CONTROL) TO ALS (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	86.1	86.1	85.0	84.3	78.7	86.9	86.9	85.8	85.1	79.5
5	87.0	87.0	85.9	85.2	79.6	87.8	87.8	86.7	86.0	80.4
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.6

SINGLE ENTRY C/Is - INTERFERENCE FROM C1P
(WITH FIXED-EIRP)* TO ALS (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	86.1	86.1	85.0	84.3	78.7	86.9	86.9	85.8	85.1	79.5
5	85.0	85.0	"	85.0	82.6	85.8	85.8	85.8	85.8	83.6
10	"	"	"	"	85.0	"	"	"	"	85.8
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 18.1°;
the interfering signal path elevation angle is 22.8°.

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TABLE 2.7

SINGLE ENTRY C/Is - INTERFERENCE FROM C2P (WITH POWER CONTROL) TO HWA (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	82.7	82.7	81.9	81.4	76.9	85.3	85.3	84.5	84.0	79.5
5	84.7	84.7	83.9	83.4	78.9	87.3	87.3	86.5	86.0	81.5
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.8

SINGLE ENTRY C/Is - INTERFERENCE FROM C2P (WITH FIXED-EIRP)* TO HWA (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	82.7	82.7	81.9	81.4	76.9	85.3	85.3	84.5	84.0	79.5
5	81.9	81.9	"	81.9	81.1	84.5	84.5	"	84.5	83.7
10	"	"	"	"	81.9	"	"	"	"	84.5
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 62.8°; the interfering signal path elevation angle is 10.6°.

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TABLE 2.9

SINGLE ENTRY C/Is - INTERFERENCE FROM HWA
(WITH POWER CONTROL) TO C2P (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing					Cross-Polar Sharing				
	C/I (dB) Exceedance Time Percentage					C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	99.4	99.4	97.4	96.3	87.1	96.8	96.8	94.8	93.7	84.5
5	100.2	100.2	98.2	97.1	87.9	97.6	97.6	95.6	94.5	85.3
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.10

SINGLE ENTRY C/Is - INTERFERENCE FROM HWA
(WITH FIXED-EIRP)* TO C2P (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing					Cross-Polar Sharing				
	C/I (dB) Exceedance Time Percentage					C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	99.4	99.4	97.4	96.3	87.1	96.8	96.8	94.8	93.7	84.5
5	97.4	97.4	"	97.4	90.1	94.8	94.8	"	94.8	87.5
10	"	"	"	"	95.1	"	"	"	"	92.5
15	"	"	"	"	97.3	"	"	"	"	94.8
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 23.1^{o};
the interfering signal path elevation angle is 58.2^{o}

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TABLE 2.11

SINGLE ENTRY C/Is - INTERFERENCE FROM BBB (WITH POWER CONTROL) TO C5P (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	66.9	66.9	63.1	61.1	44.9	66.0	66.0	62.2	60.2	44.0
5	71.9	71.9	68.1	66.1	49.9	71.0	71.0	67.2	65.2	49.0
10	75.0	75.0	71.2	69.2	53.0	74.1	74.1	70.3	68.3	52.1
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.12

SINGLE ENTRY C/Is - INTERFERENCE FROM BBB (WITH FIXED-EIRP)* TO C5P (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	66.9	66.9	63.1	61.1	44.9	66.0	66.0	62.2	60.2	44.0
5	63.1	63.1	"	62.3	46.1	62.2	62.2	"	61.4	45.2
10	"	"	"	63.1	51.1	"	"	"	62.2	50.2
15	"	"	"	"	56.1	"	"	"	"	55.2
Unlimited	"	"	"	"	63.1	"	"	"	"	62.2

* The desired signal path elevation angle is 36.6°; the interfering signal path elevation angle is 43.4°.

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TABLE 2.13

SINGLE ENTRY C/Is - INTERFERENCE FROM C5P
(WITH POWER CONTROL) TO BBB (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	81.7	81.6	73.6	69.5	35.0	80.9	80.8	72.8	68.7	34.2
5	85.5	85.4	77.4	73.1	38.8	84.7	84.6	76.6	72.3	38.0
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.14

SINGLE ENTRY C/Is - INTERFERENCE FROM C5P
(WITH FIXED-EIRP)* TO BBB (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	81.7	81.6	73.6	69.5	35.0	80.9	80.8	72.8	68.7	34.2
5	76.7	76.6	"	"	"	75.9	75.8	"	"	"
10	73.6	73.6	"	71.4	36.9	72.8	72.8	"	70.6	36.1
15	"	"	"	73.6	41.9	"	"	"	72.8	41.1
Unlimited	"	"	"	"	73.6	"	"	"	"	72.8

* The desired signal path elevation angle is 38.3^{o};
the interfering signal path elevation angle is 35.4^{o}.

TABLE 2.15

SINGLE ENTRY C/Is - INTERFERENCE FROM GUS
(WITH POWER CONTROL) TO GRL (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	57.0	57.0	54.1	52.5	39.5	56.4	56.4	53.5	51.9	38.9
5	52.0	52.0	49.1	47.5	34.5	51.4	51.4	48.5	46.9	33.9
10	47.2	47.2	44.3	42.7	29.7	46.6	46.6	43.7	42.1	29.1
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.16

SINGLE ENTRY C/Is - INTERFERENCE FROM GUS
(WITH FIXED-EIRP)* TO GRL (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	57.0	57.0	54.1	52.5	39.5	56.4	56.4	53.5	51.9	38.9
5	54.1	54.1	"	54.1	41.6	53.5	53.5	"	53.5	41.0
10	"	"	"	"	46.6	"	"	"	"	46.0
15	"	"	"	"	51.6	"	"	"	"	51.0
Unlimited	"	"	"	"	54.1	"	"	"	"	53.5

* The desired signal path elevation angle is 14.4^{o};
the interfering signal path elevation angle is 82.5^{o}.

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TABLE 2.17

SINGLE ENTRY C/Is - INTERFERENCE FROM GRL
(WITH POWER CONTROL) TO GUS (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	72.4	72.3	62.6	57.7	16.8	71.8	71.7	62.0	57.1	16.2
5	75.3	75.2	65.5	60.6	19.7	74.7	74.6	64.9	60.0	19.1
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.18

SINGLE ENTRY C/Is - INTERFERENCE FROM GRL
(WITH FIXED-EIRP)* TO GUS (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	72.4	72.3	62.6	57.7	16.8	71.8	71.7	62.0	57.1	16.2
5	67.4	67.3	"	"	"	66.6	66.5	"	"	"
10	62.6	62.6	"	57.9	17.0	62.0	62.0	"	57.3	16.4
15	"	"	"	62.6	22.0	"	"	"	62.0	21.4
Unlimited	"	"	"	"	62.6	"	"	"	"	62.0

* The desired signal path elevation angle is 81.7°;
the interfering signal path elevation angle is 14.2°.

TABLE 2.19

SINGLE ENTRY C/Is - INTERFERENCE FROM GUS
(WITH POWER CONTROL) TO CHA (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	85.1	85.1	83.2	82.1	73.4	83.5	83.5	81.6	80.5	71.8
5	90.1	90.1	88.2	87.1	78.4	88.5	88.5	86.6	85.5	76.8
10	94.9	94.9	93.0	91.9	83.2	93.3	93.3	91.4	90.3	81.6
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.20

SINGLE ENTRY C/Is - INTERFERENCE FROM GUS
(WITH FIXED-EIRP)* TO CHA (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	85.1	85.1	83.2	82.1	73.4	83.5	83.5	81.6	80.5	71.8
5	83.2	83.2	"	83.2	76.5	81.6	81.6	"	81.6	74.9
10	"	"	"	"	81.5	"	"	"	"	79.9
15	"	"	"	"	83.2	"	"	"	"	81.6
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 52.2°;
the interfering signal path elevation angle is 67.9°.

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TABLE 2.21

SINGLE ENTRY C/Is - INTERFERENCE FROM CHA
(WITH POWER CONTROL) TO GUS (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	92.9	92.8	83.1	78.2	37.3	91.6	91.5	81.8	76.9	36.0
5	94.8	94.7	85.0	80.1	79.2	93.5	93.4	83.7	78.8	37.9
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.22

SINGLE ENTRY C/Is - INTERFERENCE FROM CHA
(WITH FIXED-EIRP)* TO GUS (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	92.9	92.8	83.1	78.2	37.3	91.6	91.5	81.8	76.9	36.0
5	87.9	87.8	"	78.2	37.3	86.6	86.5	"	76.9	36.0
10	83.1	83.1	"	78.4	37.5	81.8	81.8	"	77.1	36.2
15	"	"	"	83.1	42.5	"	"	"	81.8	41.2
Unlimited	"	"	"	"	83.1	"	"	"	"	81.8

* The desired signal path elevation angle is 81.7°;
the interfering signal path elevation angle is 53.5°.

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TABLE 2.23

SINGLE ENTRY C/Is - INTERFERENCE FROM MXN
(WITH POWER CONTROL) TO ALS (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	84.5	84.5	83.4	82.7	77.1	81.5	81.5	80.4	79.7	74.1
5	88.4	88.4	87.3	86.6	81.0	85.4	85.4	84.3	83.6	78.0
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.24

SINGLE ENTRY C/Is - INTERFERENCE FROM MXN
(WITH FIXED-EIRP)* TO ALS (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	84.5	84.5	83.4	82.7	77.1	81.5	81.5	80.4	79.7	74.1
5	83.4	83.4	"	83.4	81.0	80.4	80.4	"	80.4	78.0
10	"	"	"	"	83.4	"	"	"	"	80.4
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

* The desired signal path elevation angle is 18.1^{o};
the interfering signal path elevation angle is 9.3^{o}.

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TABLE 2.25

SINGLE ENTRY C/Is - INTERFERENCE FROM ALS
(WITH POWER CONTROL) TO MXN (WITH FIXED-EIRP)*

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	92.1	92.1	88.2	86.2	69.1	89.1	89.1	85.2	83.2	66.1
5	93.2	93.1	87.1	85.1	68.0	88.0	88.0	84.1	82.1	65.0
10	"	"	"	"	"	"	"	"	"	"
15	"	"	"	"	"	"	"	"	"	"
Unlimited	"	"	"	"	"	"	"	"	"	"

TABLE 2.26

SINGLE ENTRY C/Is - INTERFERENCE FROM ALS
(WITH FIXED-EIRP)* TO MXN (WITH POWER CONTROL)

Power Control Dynamic Range (dB)	Co-Polar Sharing C/I (dB) Exceedance Time Percentage					Cross-Polar Sharing C/I (dB) Exceedance Time Percentage				
	90	95	99	99.5	99.9	90	95	99	99.5	99.9
0	92.1	92.1	88.2	86.2	69.1	89.1	89.1	85.2	83.2	66.1
5	88.2	88.2	"	87.3	70.2	85.2	85.2	"	84.3	67.2
10	"	"	"	88.2	75.2	"	"	"	85.2	72.2
15	"	"	"	"	80.2	"	"	"	"	77.2
Unlimited	"	"	"	"	88.2	"	"	"	"	85.2

* The desired signal path elevation angle is 56.9^{0};
the interfering signal path elevation angle is 14.6^{0}.

III. FEEDER LINK POLARIZATION ANALYSIS RESULTS

INTRODUCTION

The performance of feeder links to nominally co-located satellites with overlapping coverage areas when orthogonal polarizations are used differs for linear and circular polarizations. This difference in the performance of linearly and circularly polarized feeder links is evaluated below. The approach in Appendix A was used to determine the relative performance of linearly and circularly polarized feeder links in the presence of interference from an orthogonally polarized feeder link. The increases in equivalent antenna gains (Appendix B) during ice and rain depolarization events for linear and circular polarizations are discussed first. The relative performance of feeder links using linear and circular polarization is then considered. Conclusions are given in Section IV.

EQUIVALENT GAIN DURING DEPOLARIZATION EVENTS

Figures 3.1, 3.2 and 3.3 show the statistical equivalent gain increases over interfering signal paths for linear and circular polarizations. The effects of depolarization have been magnified by assuming 10^{0} interference path elevation angles and earth stations at sea level. These assumptions lead to lower cross polarization discrimination (XPD) values than higher elevation angles and earth station heights above sea level. A latitude of 36^{0} was used to determine the rain heights and rain zones B, D, K and M were considered (Appendix D), which are representative of situations

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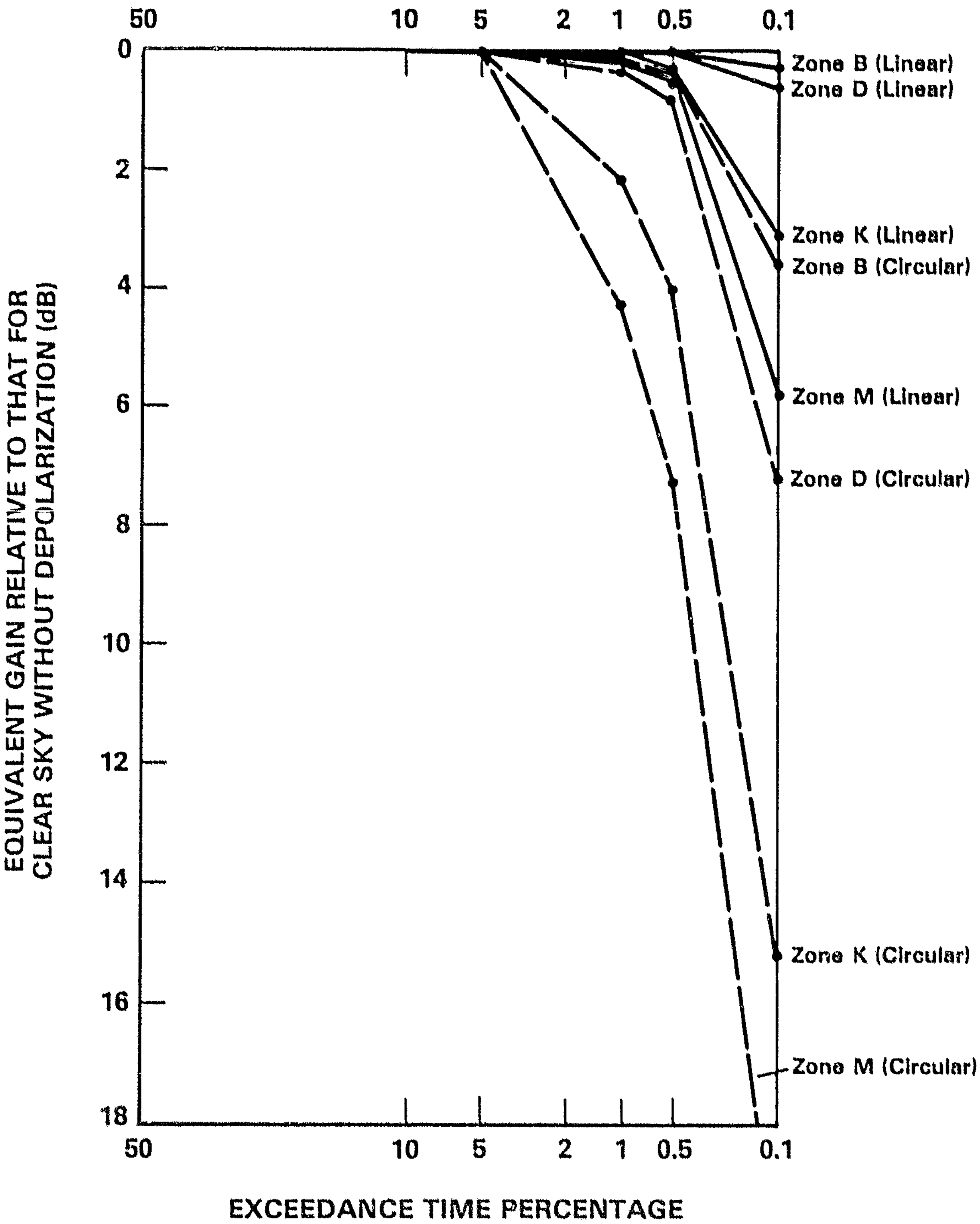

FIGURE 3.1. EQUIVALENT GAIN INCREASES DUE TO DEPOLARIZATION (SATELLITE SEPARATION = 0.1°)

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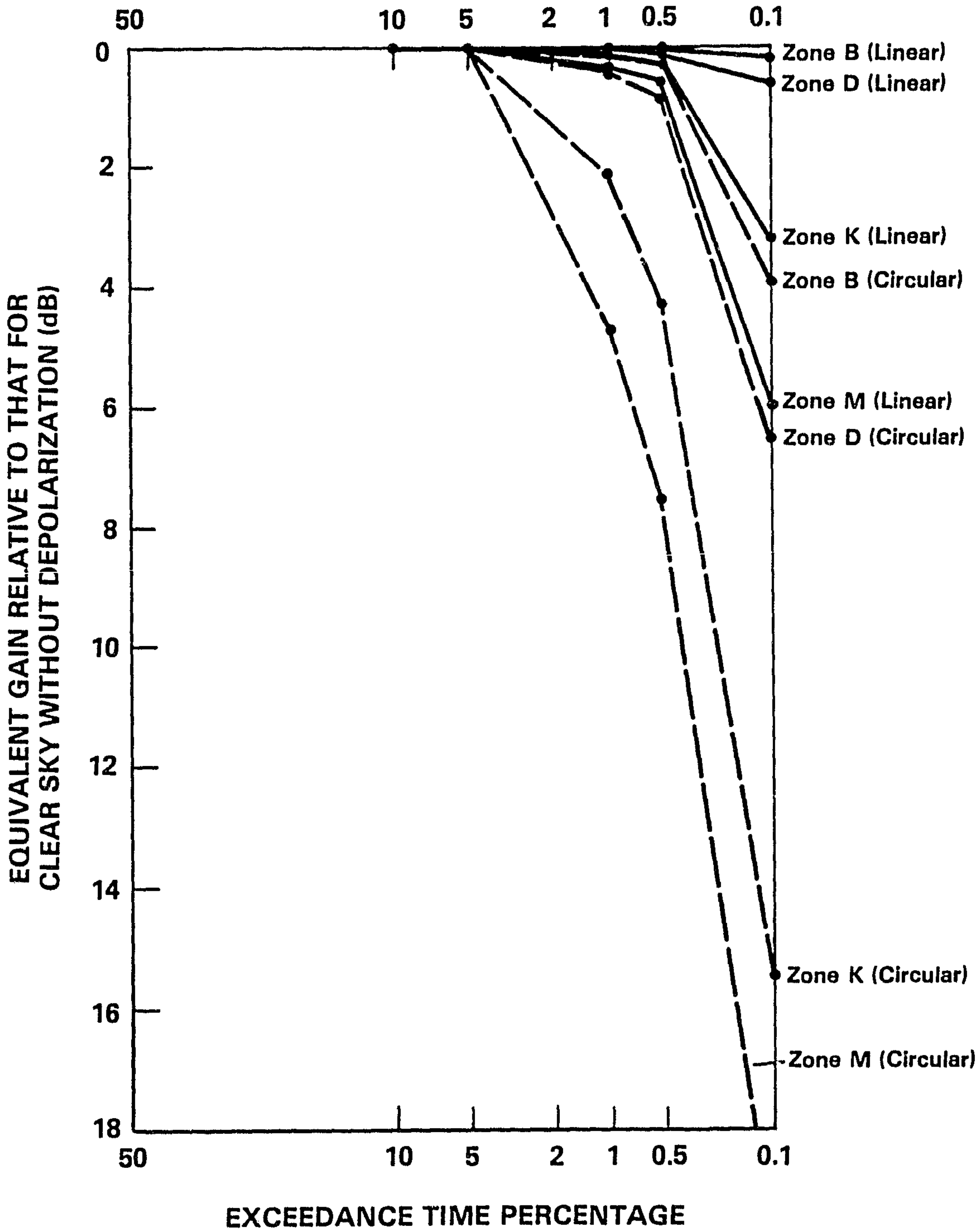

FIGURE 3.2. EQUIVALENT GAIN INCREASES DUE TO DEPOLARIZATION (SATELLITE SEPARATION = 0.3^{o})

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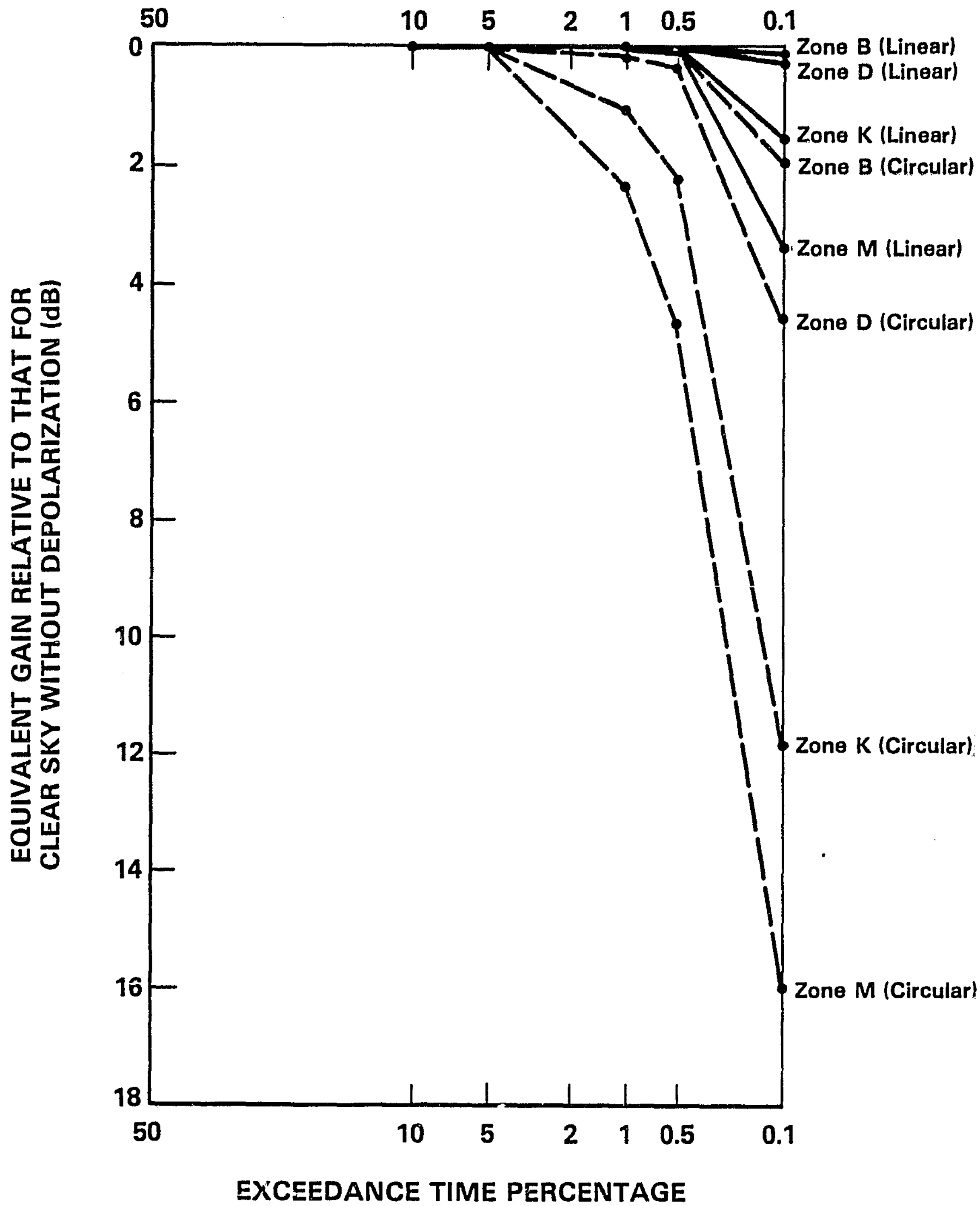

FIGURE 3.3. EQUIVALENT GAIN INCREASES DUE TO DEPOLARIZATION (SATELLITE SEPARATION = 0.5°)

that would be encountered in the near-worst-case for feeder links from the continental United States. Linearly polarized links are assumed to be ideally vertical or horizontal at the earth station site. That is, the polarization vector is in the plane of the satellite, site and earth center (vertical) or tangent to the earth (horizontal). Nominal U.S. time zone coverage is assumed for the satellite feeder link antenna. All relevant antenna gains are shown in Table 3.1.

TABLE 3.1
ANTENNA GAINS (dBi) USED IN THE POLARIZATION ANALYSIS
(CPM VALUES)

	Satellite Spacing		
Gain Component	0.1^{o}	0.3^{o}	0.5^{o}
CO-POLAR TRANSMIT	56.0	47.0	36.5
CROSS-POLAR TRANSMIT	29.0	19.5	15.0
CO-POLAR RECEIVE	35.0	35.0	35.0
CROSS-POLAR RECEIVE	5.0	5.0	5.0

Figures 3.1, 3.2 and 3.3 show that the equivalent gain on an interference path increases during depolarization when orthogonal polarizations are used in the desired and interfering link. The dashed lines and solid lines are log-normal interpolations for circular and linear polarizations, respectively, between data for 90 percent, 95 percent, 99 percent, 99.5 percent and 99.9 percent of the worst-month. The depolarization conditions associated the five time percentages are as follows:

90 percent	:	no depolarization.
95 percent	:	ice-induced depolarization only, XPD reductions of 2 dB for rain zones B and K; 4 dB for zone D; and 5 dB for zone M.

99 -99.9 percent : ice-induced depolarization (as for 95 percent) 5 dB for zone M.

There is considerable uncertainty in data for 95 percent of the worst-month due to the lack of applicable data on ice depolarization events. The XPD reductions due to atmospheric ice crystals in the absence of rain could be much larger than the values assumed herein. However, this would not necessarily affect the equivalent gain increases for 95 percent of the worst-month in a significant way. The equivalent gain increases due to only ice-induced depolarization effects for 95 percent of the worst-month were much less than 1 dB for the assumed XPD reductions (i.e., 2-5 dB).

RELATIVE PERFORMANCE OF LINEAR AND CIRCULAR POLARIZATIONS

The increases in equivalent gain on the interfering signal path must be greater than any simultaneous increases in rain attenuation in order to produce increased interference during rain. Figure 3.4 shows the rain attenuations associated with the interference paths for Figures 3.1, 3.2 and 3.3. These attenuations were never exceeded by the (simultaneous) increase in equivalent gain. Thus, the C/Is in the orthogonally polarized victim feeder links are dependent only on desired signal fading (Appendix A, Equation 6) when the victim and interfering links have independent radiometeorological conditions. This independence of radiometerological conditions on the victim and interfering feeder links is realized when the associated earth stations are sufficiently separated in distance, as discussed in Appendix A. Thus, when the earth stations associated with the victim and interfering feeder links are sufficiently separated in distance, feeder link performance degradation during rain in terms of C/I is independent of the choice of polarization.

On the other hand, if the radiometerological conditions on the victim and interfering feeder links are highly correlated, the short-term C/I degradation due to depolarization may differ for circular and linear polarizations. For example, if both the orthogonally polarized feeder link earth and space stations are nominally co-located, the Cs and Is in their

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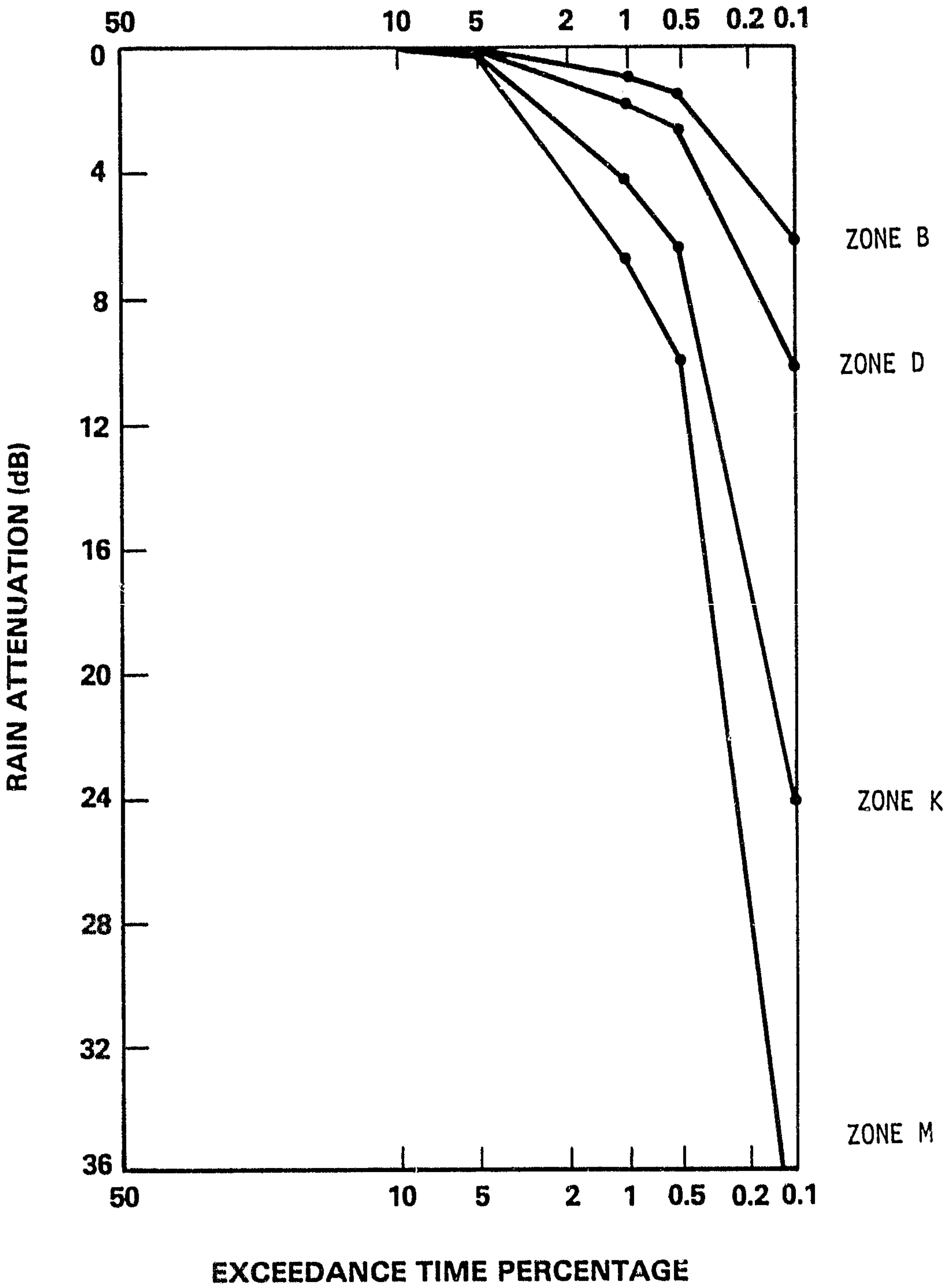

FIGURE 3.4. RAIN ATTENUATIONS ASSOCIATED WITH THE INTERFERENCE PATHS IN FIGURES 3.1, 3.2 AND 3.3.

respective links will be correlated. However, the statistical C/I variations could be expected to differ with the choice of polarization type. The relative C/Is for this case are illustrated for the four representative U.S. rain zones in Figures 3.5 through 3.8, where the maximum potential C/I improvement from using linear rather than circular polarization is given.

Table 3.2 shows the maximum potential C/I improvements from using linear rather than circular polarization that correspond with 99% of the worst-month. The improvements could be as great as those in Table 3.2 only if the victim and interfering feeder links encounter identical rain conditions. In a practical sense, this worst-case situation might be approximated by nominally co-located earth stations (and satellites).

TABLE 3.2
MAXIMUM POSSIBLE C/I IMPROVEMENTS (dB)
FROM USING LINEAR RATHER THAN CIRCULAR
POLARIZATION - 99% OF THE WORST-MONTH

	Satellite Spacing		
Rain Zone	0.1°	0.3°	0.5°
B	0.2	0.1	0.0
D	0.3	0.3	0.2
K	2.0	2.2	0.9
M	4.2	4.6	2.4

It can be seen in Table 3.2 that for very close satellite spacing a significant improvement can be realized during the relatively heavy rain associated with 99% of the worst-month in rain zones K and M (Appendix D). There is no appreciable improvement in C/I for the relatively dry climates (zones B and D). Also, it is apparent that the potential improvement generally diminishes as satellite spacing is increased, although there is a small initial increase in improvement in the wetter climates. This reduction

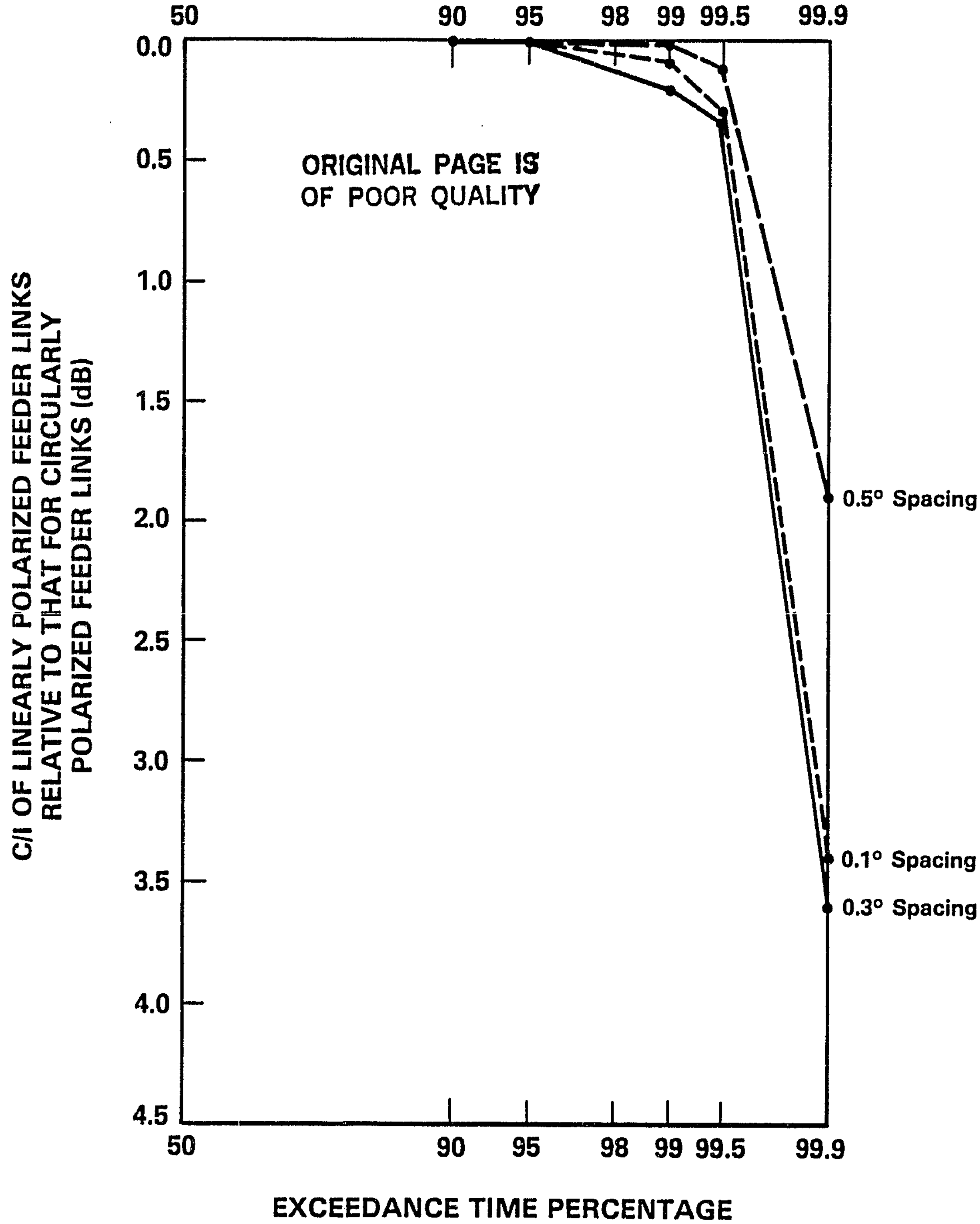

FIGURE 3.5. MAXIMUM IMPROVEMENT IN C/I FROM USING LINEAR RATHER THAN CIRCULAR POLARIZATIONS IN THE PRESENCE OF AN ORTHOGONALLY POLARIZED INTERFERER (RAIN ZONE B)

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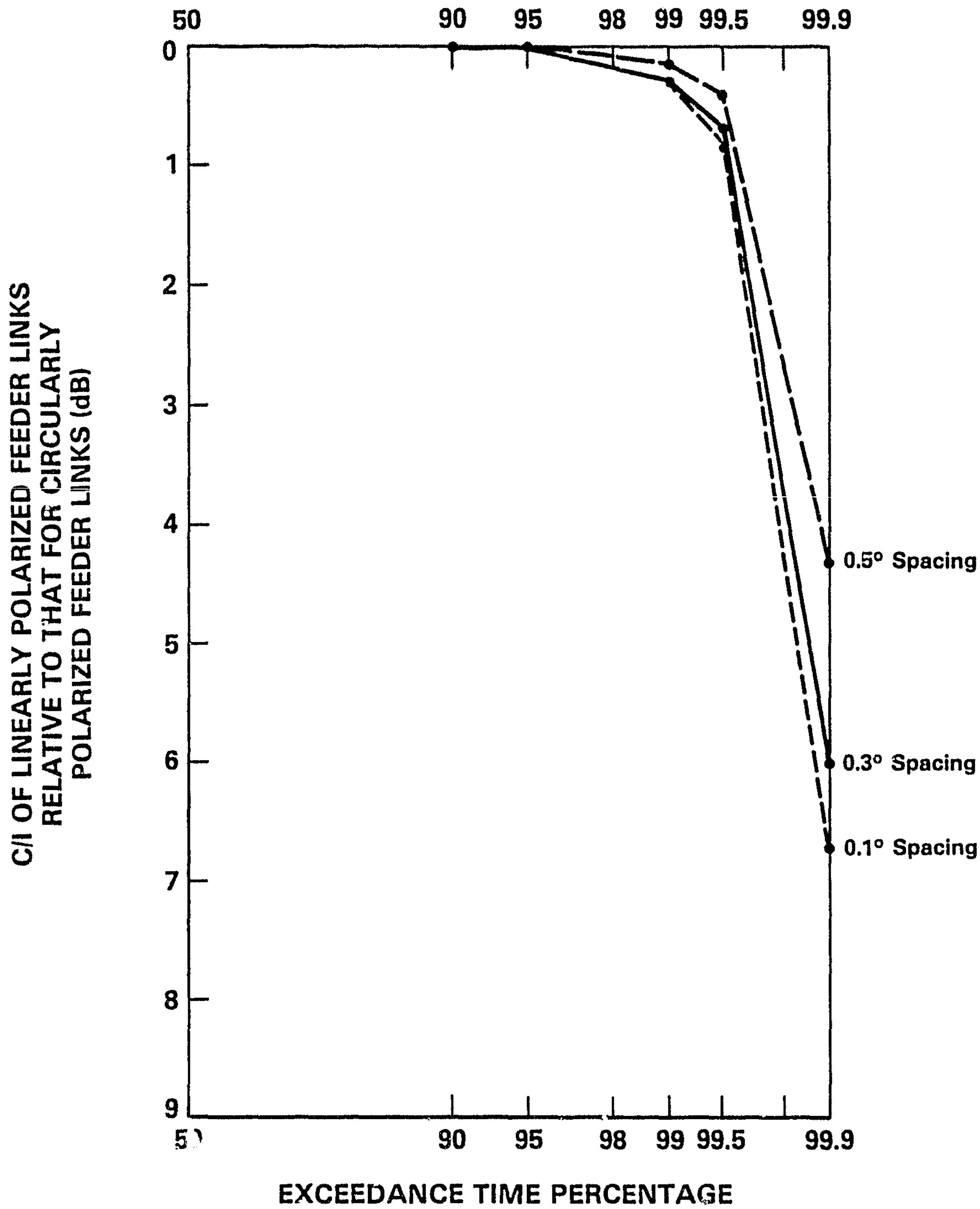

FIGURE 3.6. MAXIMUM IMPROVEMENT IN C/I FROM USING LINEAR RATHER THAN CIRCULAR POLARIZATIONS IN THE PRESENCE OF AN ORTHOGONALLY POLARIZED INTERFERER (RAIN ZONE D)

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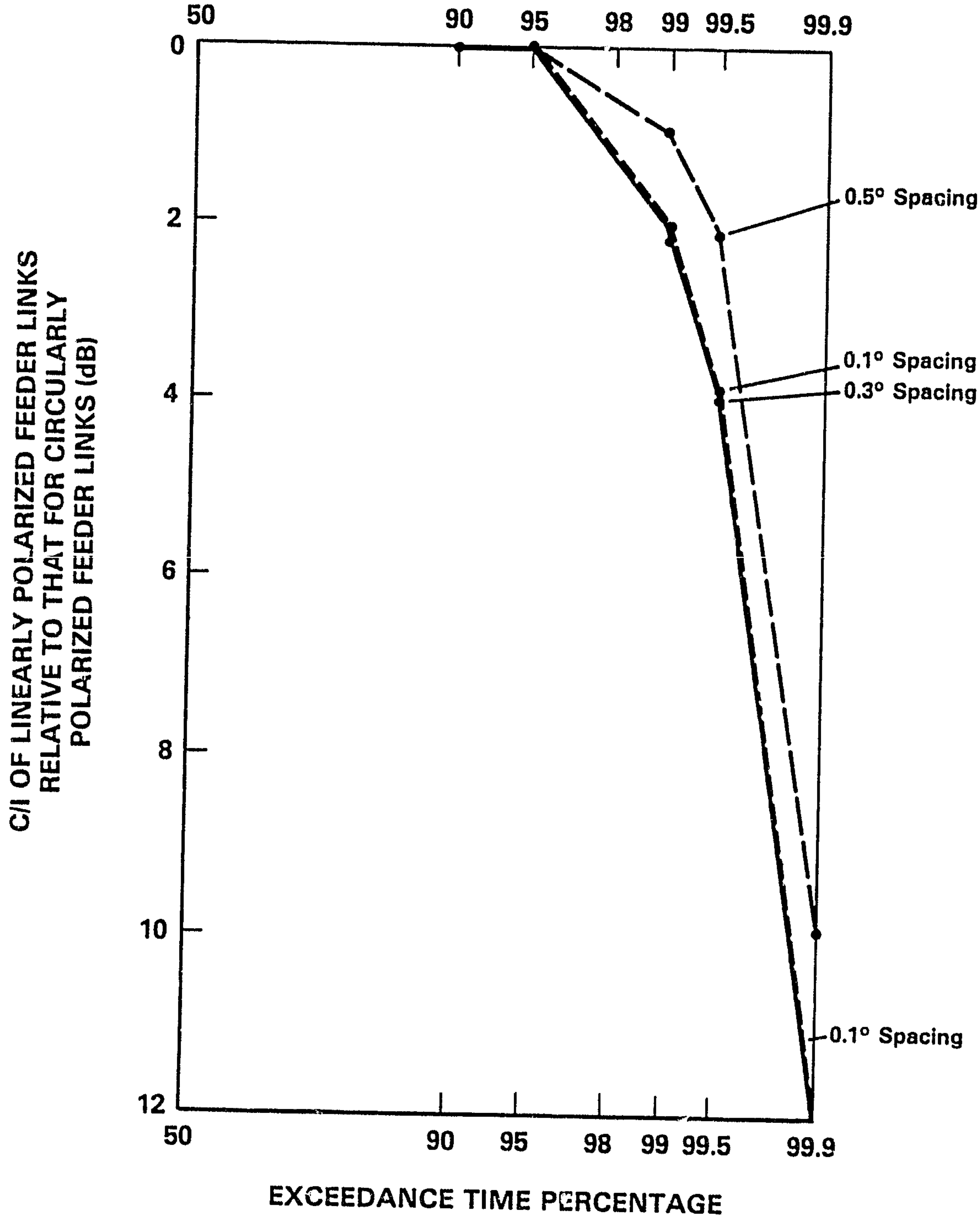

FIGURE 3.7. MAXIMUM IMPROVEMENT IN C/I FROM USING LINEAR RATHER THAN CIRCULAR POLARIZATIONS IN THE PRESENCE OF AN ORTHOGONALLY POLARIZED INTERFERER (RAIN ZONE K)

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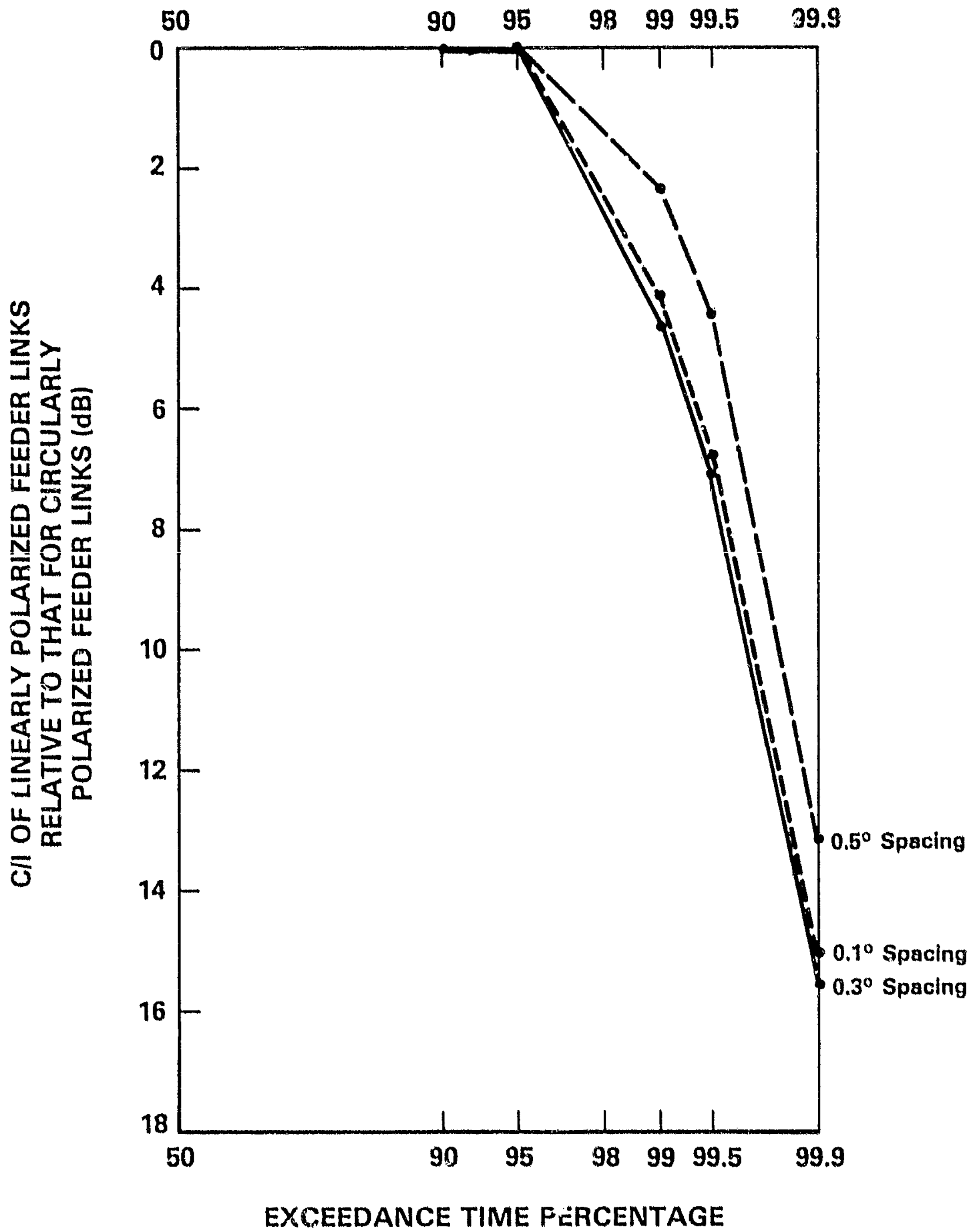

FIGURE 3.8. MAXIMUM IMPROVEMENT IN C/I FROM USING LINEAR RATHER THAN CIRCULAR POLARIZATIONS IN THE PRESENCE OF AN ORTHOGONALLY POLARIZED INTERFERER (RAIN ZONE M)

in improvement with increasing satellite spacing results from reductions in earth station antenna XPD with increasing off-axis angles. The rain attenuations associated with the significant improvements in zones K and M were 4.3 dB and 6.8 dB, respectively (99% values), which exceed the concomitant increases in equivalent gain.

SUMMARY OF THE COMPARISON BETWEEN LINEAR AND CIRCULAR POLARIZATIONS

The choice of polarization for feeder links to nominally co-located satellites has no effect on their C/Is during depolarization, assuming comparable performance during clear-sky, when the orthogonally polarized victim and interfering links have uncorrelated radiometeorological conditions. When the radiometeorological conditions on the orthogonally polarized victim and interfering links have uncorrelated radiometeorological conditions. When the radiometeorological conditions on the orthogonally polarized victim and interfering links are correlated, as would occur for nominally co-located earth stations, linear polarization offers some C/I improvement over circular polarization during rain. However, such improvements are small (less than 0.3 dB) except in wet climates (zones K and M) under near-worst-case conditions (e.g., geometries that result in relatively high signal fading).

IV. CONCLUSIONS AND RECOMMENDATIONS

INTRODUCTION

The analytical methods and data base, as delineated in Appendicies A through D, have been used in separate analyses of feeder link power control and polarization. The results of these analyses are given in Sections II and III. Several conclusions regarding BSS feeder link power control and polarization have been made on the basis of these results. Also, since the power control analysis was necessarily of limited scope, recommendations for further study have been made. These conclusions and recommendations are presented below for the power control analysis first, then for the polarization analysis.

EFFECTS OF POWER CONTROL ON FEEDER LINK PERFORMANCE

The following conclusions pertain to feeder links that experience statistically independent radiometeorological conditions, as would occur in the context of international planning or national BSS implementation where the earth stations are sufficiently separated in distance.

Conclusions

- A feeder link using power control causes less degradation in terms of statistical C/Is than a fixed-EIRP feeder link that has similar C/N availability.

- If power control is used to increase feeder link availability over that of a fixed-EIRP link, the power-controlled link as an interferer generally causes less C/I degradation than the fixed-EIRP link despite its higher short-term power levels. The exceptions to this are unrealistically worst-case situations where the degradation with power control exceeds that for fixed-EIRP for insignificant percentages of time (i.e., percentages that are much less than those associated with the C/I availability objective of 1% of the worst-month).

- A feeder link using power control to the maximum practical extent, (where power increases equal rain attenuation increases), will operate near its short-term C/N and C/I thresholds (i.e., 99% of the time value) for most of the time. This is believed to be acceptable, since these thresholds correspond with excellent reception (CPM). Alternative power control system parameters (i.e., higher baseline power) will enable operation above these thresholds most of the time (i.e., when there is no rain).

- A feeder link using power control can realize considerable reductions in transmitter power levels most of the time (i.e., 90% of the time), yet still meet (or exceed) availability requirements.

- The precipitation scatter interference mechanism was not considered in this analysis, but might potentially alter the results of this analysis. The investigation in Appendix C indicates that this mechanism could result in higher interference levels than have been predicted in this analysis using conventional methods. This is of course important whether power control is used or not. However, rain scatter interference appears to be relatively significant only in cases where conventional analyses indicate very low interference levels - rain scatter might perhaps greatly increase the interference, but not to significant levels.

Recommendations

- The precipitation scatter interference mechanism should be investigated further in the context of sharing between satellite networks. The uncertainty involved with the application of the CCIR model to sharing between satellite networks, as in Appendix C, prohibits definitive conclusions in this report. However, the provisional analysis shows that this matter could be of great importance.

- If feeder link availabilities greater than those afforded in the forthcoming RARC-83 plan are to be sought through the use of power control, the interference analyses in support of such deviations from the plan should consider all statistical single and multiple interference entry effects. This is important because the implications of designing BSS feeder links for higher-than-planned availabilities may not be apparent in single entry interference analyses due to the joint statistics of the desired signal and the multiple interference entries.

RELATIVE PERFORMANCE OF LINEARLY AND CIRCULARLY POLARIZED FEEDER LINKS IN THE PRESENCE OF AN ORTHOGONALLY POLARIZED FEEDER LINK TO NOMINALLY CO-LOCATED SATELLITES HAVING OVERLAPPING COVERAGE AREAS

Conclusions

- Depolarization events can result in significantly lower C/Is for circularly polarized links than linearly polarized links, for a given exceedance time percentage p, only under the following conditions:

  - The earth stations in the victim and interfering links experience similar rain conditions simultaneously (earth stations separated by less than the rain-correlation distance); and

- The earth stations are located in a relatively wet climate (e.g., rain zones K or M); and

- The earth station antenna elevation angles are low enough to result in significant short-term attenuation and concomitant XPD reductions (e.g., elevation angle of 20^o from mid-latitude sites where attenuation for 99% of the worst-month exceeds about 4 dB and satellites are spaced by less than 0.5^o).

- As the interference path elevation angle increases, the maximum potential C/I performance differential for orthogonal linear and circular polarizations decreases.

- If the alignment of the linear polarization vector at the interfering earth station site is not ideally vertically or horizontally oriented, the maximum possible C/I performance differential between linear and circular polarizations will be less than those in Figures 3.5-3.8.

APPENDIX A

ANALYTICAL METHODS

GENERAL

The performance of a feeder link is determined by the carrier power level (C), the interference power level (I), and the noise power level (N) at the satellite. These parameters are random variables; however, the variation in N with time is negligible, especially in comparison to the variations of C and I. Consequently, N can be assumed to be constant and statistical considerations are required for only I and C. The parameter of interest for power control and polarization considerations is the carrier-to-interference power ratio (C/I) exceeded for large percentages of the worst-month.

Propagation and equipment factors are introduced in this Appendix first, then the analytical approaches for the assessments of power control and polarization are presented. Measures have been taken to encompass the effects of all propagation mechanisms that are relevant for the evaluation of C/I at large exceedance percentages. The analytical approaches treat any combinations of victim and interfering feeder link polarization and power control at 17.5 GHz, althought the methods are generally applicable over the range of about 15 GHz to 20 GHz.

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PROPAGATION FACTORS

With or without power control, the variation of C/I with time results from several propagation effects. Statistics for C and I and a knowledge of their correlation can be used to determine a C/I distribution. The CCIR has compiled the general considerations for the propagation mechanisms affecting earth-to-space paths.[1] The CCIR approach is to calculate C and I from yearly statistical data, then convert the resulting statistics to worst-month values. The following functional relationships apply:

$$C(p_c) = f\left[L_{wv}, L_r, L_{fs} \right] \tag{1}$$

$$I(p_i) = f\left[(L_{wv}, L_r, L_{fs}, XPD), (L_{rs}) \right] \tag{2}$$

where

$C(p_c)$, $I(p_i)$ = desired signal and interference power levels (dBW) exceeded for p_c and p_i percent of the worst-month, respectively;

L_{wv} = water vapor attenuation (dB);

L_r = precipitation attenuation (dB);

L_{fs} = free space loss (dB);

XPD = cross-polar discrimination (dB); and

L_{rs} = transmission loss (dB) and cross-polarization effect (dB) on the precipitation scatter path.

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[1] /CCIR, Propagation Data Required for Space Telecommunication Systems, Report 564-1 (MOD F), Doc. 5/1044, Geneva, Switzerland, 28 September 1981.

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Equation 1 does not contain an XPD factor since XPD effects on desired carrier reception are negligible. The subset of four factors in Equation 2 pertains to the "direct" earth station-to-victim space station path, whereas the remaining factor L_{rs} corresponds with an "indirect" path. Figure A.1 illustrates a possible worst-case scenario for interference from an earth station employing power control. The relevant short-term propagation mechanisms are shown.

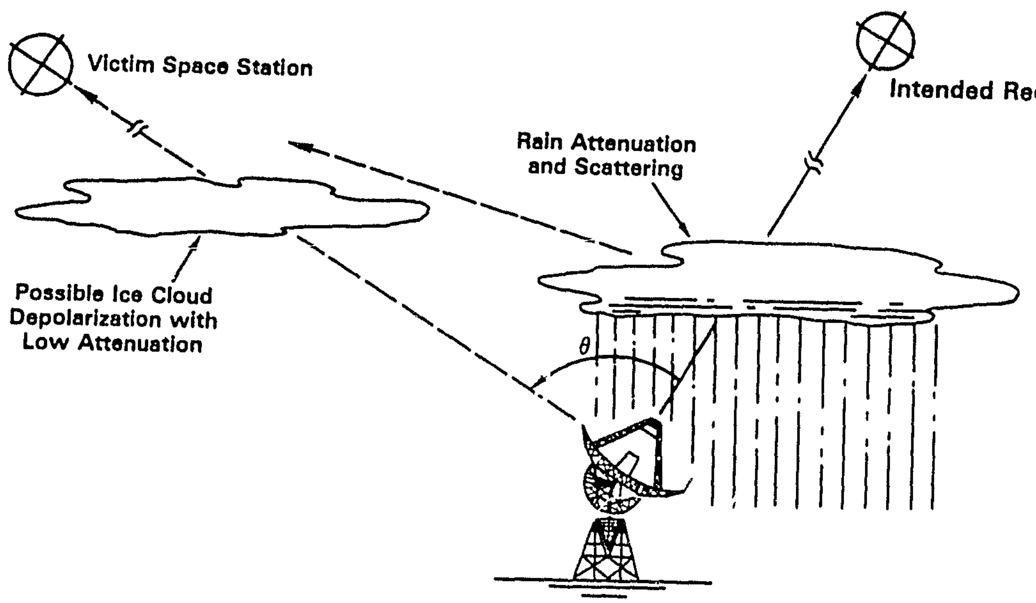

FIGURE A.1. ILLUSTRATION OF POSSIBLE WORST-CASE SCENARIO FOR INTERFERENCE FROM ONE EARTH STATION

Feeder link beam divergence, scintillation, Faraday rotation, dispersion, and multipath effects are assumed to be negligible and, hence, not included in Equations 1 and 2. This assumption is valid at 17.5 GHz for earth station antenna elevation angles greater than about ten degrees. In addition, differential oxygen absorption over the desired signal and direct and indirect interfering signal paths is assumed to be insignificant (i.e., they are small and will approximately cancel in the C over I ratio).

Water Vapor Attenuation

The long-term (i.e., 10 to 90 percent of time exceedances) statistics of $C(p_C)$ and $I\ (p_i)$ are virtually dependent only on water vapor attenuation. The CCIR has shown that the water vapor density is approximately Gaussian with a standard deviation equal to about one-quarter of the mean.[2] Consequently, there can be significant variability of C or I from earth stations in climates having high mean water vapor concentrations. It can be assumed that there is some correlation between precipitation and the moderate to high values of water vapor density, although many climates exhibit high absolute humidity (high water vapor density) in the absence of precipitation.

It has been observed in the CCIR and URSI literature that measurements of precipitation attenuation do not explicitly exclude the associated water vapor attenuation. For the purposes of this analysis, it is assumed that all short-term (large exceedance percentages) water vapor attenuation effects are encompassed in the results of precipitation attenuation calculations. The CCIR method for determining water vapor attenuation[3] is used only for exceedance time percentages that do not involve precipitation attenuation (i.e., typically $p < 98$ percent).

Precipitation Attenuation

Rainfall effects dominate the statistics of precipitation attenuation, although clouds, fog, hail and snow are attenuating media.[4] The CCIR has developed an empirical slant-path rain attenuation model[5] that has been used in this analysis. As was previously noted, the model is assumed

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[2] CCIR Radiometeorological Data, Report 563-1 (MOD F), Doc. 5/5049, Geneva, Switzerland, 10 September 1981.

[3] CCIR, Attenuation by Atmospheric Gases, Report 719 (MOD F), Doc. 5/1027, Geneva, Switzerland, 15 October 1981.

[4] CCIR, Attenuation by Precipitation and Other Atmospheric Particles, Report 721 (MOD F), Doc. 5/1029, Geneva, Switzerland, 28 September 1978.

[5] CCIR, Technical Bases for the Regional Administrative Radio Conference 1983 for the Planning of the Broadcasting-Satellite Service in Region 2, Geneva, Switzerland, 1982.

to include the effects of short-term water vapor attenuation. The dependent variables are the slant path elevation angle, earth station height above mean sea level, and climate-dependent statistical radiometeorological parameters (rain rate and height of the 0° C isotherm as in Appendix D).

Free Space Loss

Free space loss between isotropic antennas is a basic transmission loss that is a constant for a given frequency and distance.[6] The maximum frequency difference for adjacent channels is negligibly small and a single frequency of 17.5 GHz could be used for all free space loss calculations with negligible error. The difference in distances on wanted carrier and interfering signal paths to the geostationary orbit can produce up to about a 1.5 dB difference in free space losses. A free space loss of 209.3 dB has been used when determining feeder link C/I.

Cross-Polarization

The effects of depolarization on an interfering signal path are usually expressed in terms of cross-polarization discrimination (XPD). XPD is the ratio of the co-polarized to cross-polarized received signals when only one polarization is transmitted. Depolarization of emissions on earth-to-space paths can be induced by precipitation or multipath propagation mechanisms. The most severe multipath-induced depolarization is associated with multipath fading.[7] However, multipath-induced depolarization can be disregarded since earth station antenna elevation angles are assumed to be sufficiently high to preclude multipath effects. On the other hand, precipitation-induced depolarization levels can result in significant changes in the XPD of a satellite against interfering emissions. The precipitations

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[6] CCIR, "Calculation of Free Space Loss," Recommendation 525, Propagation in Non-Ionized Media, Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

[7] CCIR, Cross-Polarization due to the Atmosphere, Report 722 (MOD F), Doc. 5/5005, Geneva, Switzerland, 7 September 1981.

that have been found to cause significant depolarization are rain, ice crystals, and snow.[8, 9]

A residual XPD level (no depolarization) of over 40 dB typically exists on the wanted carrier link during clear sky conditions (i.e., main beam-to-main beam coupling). However, when the satellite and earth station main beams are not aligned to each other, the XPD can be relatively low. Earth station and satellite antenna characteristics and their alignment geometries establish the residual XPD level, which can then be used to afford isolation between feeder links during the absence of precipitation depolarization effects. For example, adjacent satellites might use cross-polarized feeder links to achieve isolation. In that case, the XPD on each interference path could provide a considerable reduction of interference between feeder links. However, the XPD on one interference path could fall well below the baseline (no depolarization) level during precipitation depolarization events (e.g., ice cloud on interference path). The analytical treatment of XPD and depolarization effects is described in Appendix B.

Worst-Month Statistics

The CCIR propagation analyses use average-year radiometeorological data. Such data is much more commonly available for particular locations than worst-month data, since worst-month data requires considerable processing of data measured over a somewhat longer time period. A worst-month statistic is the highest monthly probability of exceeding a threshold in one year (12 consecutive months). It applies to a period of 30 consecutive days, but the month to which the worst-month statistic pertains may vary from one threshold to another. Worst-month statistics are the average of the annual worst-month values determined from many years of data.[10]

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[8] Ibid.

[9] Hendry, A., McCormick, G.C., and Antar, Y.M.N., "Differential Propagation Constants on Slant Paths Through Snow as Measured by 16.5 GHz Polarization Diversity Radar," (Pre-prints of papers), URSI Commission F Symposium, Lennoxville, Canada, May 1980.

[10] CCIR, Worst-Month Statistics, Report 723 (MOD F), Doc. 5/5028, Geneva, Switzerland, 9 September 1981.

The CCIR approach to determining worst-month propagation effects for rain attenuation is to first calculate an attenuation value using average-year data, then perform a conversion of the associated yearly time percentage to obtain the worst-month statistics.[11] The conversions are climate- or location-specific, depending on the desired degree of generalization. However, since limited data is available for even climate-specific conversions, a universal climate-independent conversion has been provisionally accepted.[12] The CCIR universal conversion is conservative, in that predicted carrier power levels will be lower and interference powers higher than actual values for a given worst-month time percentage for most areas. This approach is used herein. Again, it is important to note that extensive measurements have shown the relationship between average-year and worst-month statistics to be highly dependent on location.[13]

The conversion of average-year to worst-month statistics may not be the same for radiometeorological effects other than rain attenuation. For example, XPD, rain scatter, and atmospheric absorption could exhibit radically different average-year to worst-month relationships. This analysis is, however, proceeding to align the cumulative distribution of C/I to rain statistics. Consequently, the provisional assumption is made that the universal conversion of rain rate/attenuation statistics applies equally to all short-term propagation effects.

Rain Scatter

Rain scatter effects have not been studied in the context of feeder link sharing.[14] Consequently, an original approach to this potential problem has been developed. This approach and the general results are presented in Appendix C.

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[11] CCIR, Propagation Data Required for Space Telecommunication Systems, Report 564-1 (MOD F), Doc. 5/1044, Geneva, Switzerland, 28 September 1981.

[12] Ibid.

[13] Segal, B., High Intensity Rainfall Statistics for Canada, Communications Research Centre Report No. 1329-E, Ottawa, November 1979.

[14] Based on an extensive literature search and queries of two recognized experts on rain scatter.

Appendix C shows that interference generated by the rain scatter mechanism can be significant in feeder link sharing at 17.5 GHz when the separation between satellites is greater than about 5^{0}. Rain scatter might produce significant interference contributions in relation to the direct earth station sidelobe-to-victim satellite interference. In such cases, however, the total potential interference power levels from both the direct and rain scatter paths will likely be negligibly small. Only power control and polarization analysis results without rain scatter effects are given since there is some uncertainty associated with the utility of the CCIR rain scatter model in this application.

EQUIPMENT FACTORS

The static and dynamic characteristics of a feeder link power control system affect the C/I. A typical power control system might consist of constant-power narrowband downlink beacons aboard the satellite, a beacon receiver system, a downlink/uplink frequency/attenuation scaling system, and a variable output feeder link transmitter. The downlink beacon signals would be subject to the same propagation attenuation mechanisms as the feeder link, and the received beacon signal powers could be processed through appropriate algorithms to control the feeder link EIRP. The feeder link EIRP would be at a constant baseline level when the received feeder link carrier is above a threshold level. This type of open-loop power control system will be considered in the analysis.

The baseline EIRP is assumed to be high enough so that a desired long-term C/N is exceeded most of the time, assuming the highest noise power level to be present. When it is predicted that the feeder link attenuation is great enough to cause the baseline received carrier to fall below a threshold level, the earth station EIRP is boosted to maintain the required C/N, except when the power control dynamic range is exceeded.

The dynamic characteristics of a power control system include the system transient response and the predicted attenuation vs. EIRP boost relationship. It is assumed that all system response delay times are negligibly small and the EIRP boost variations match predicted attenuation variations on a dB-for-dB basis when power control is activated. In reality,

there is a minimum system response time delay that includes a small two-way attenuating medium - to-earth station propagation time and equipment response delays. The sum of these delays would have a negligible effect on the worst-month cumulative distribution of the received carrier power.

An alternative power control system design might not attempt to match feeder link attenuation with a dB-for-dB increase in EIRP. Rather, the EIRP boost might intentionally only overcome a portion of the attenuation, thereby allowing a controlled drop in C as attenuation increases. An infinite number of possibilities exist with various power control activation thresholds and EIRP vs. predicted attenuation relationships. These alternative design concepts will not be considered in the analysis.

The feeder link earth stations without power control facilities use a constant EIRP that is sufficiently high to provide the required C/N for all but acceptably small percentages of the worst-month. That is, feeder link signal attenuations that are present during a specified availability time percentage do not cause the C/N to fall below an associated threshold level.

Power Control Activation Threshold

The activation threshold could be expected to be chosen so that the power control system will not respond to small long-term attenuations that occur for large time percentages (e.g., water vapor variability, water clouds). The choice of an activation threshold could also be affected by the maximum practicable EIRP boost. That is, operation at a higher baseline EIRP (power control not activated) can lower the maximum EIRP boost required to meet an availability objective. Figure A.2 illustrates these factors. It is assumed in this study that the activation threshold is dependent on climate and geometry.

Availability Requirement Factors

Feeder link availability can be specified in terms of a C/N and its associated exceedance time percentage. Two such criteria can be specified to provide excellent link quality for most of the time and a lower but acceptable

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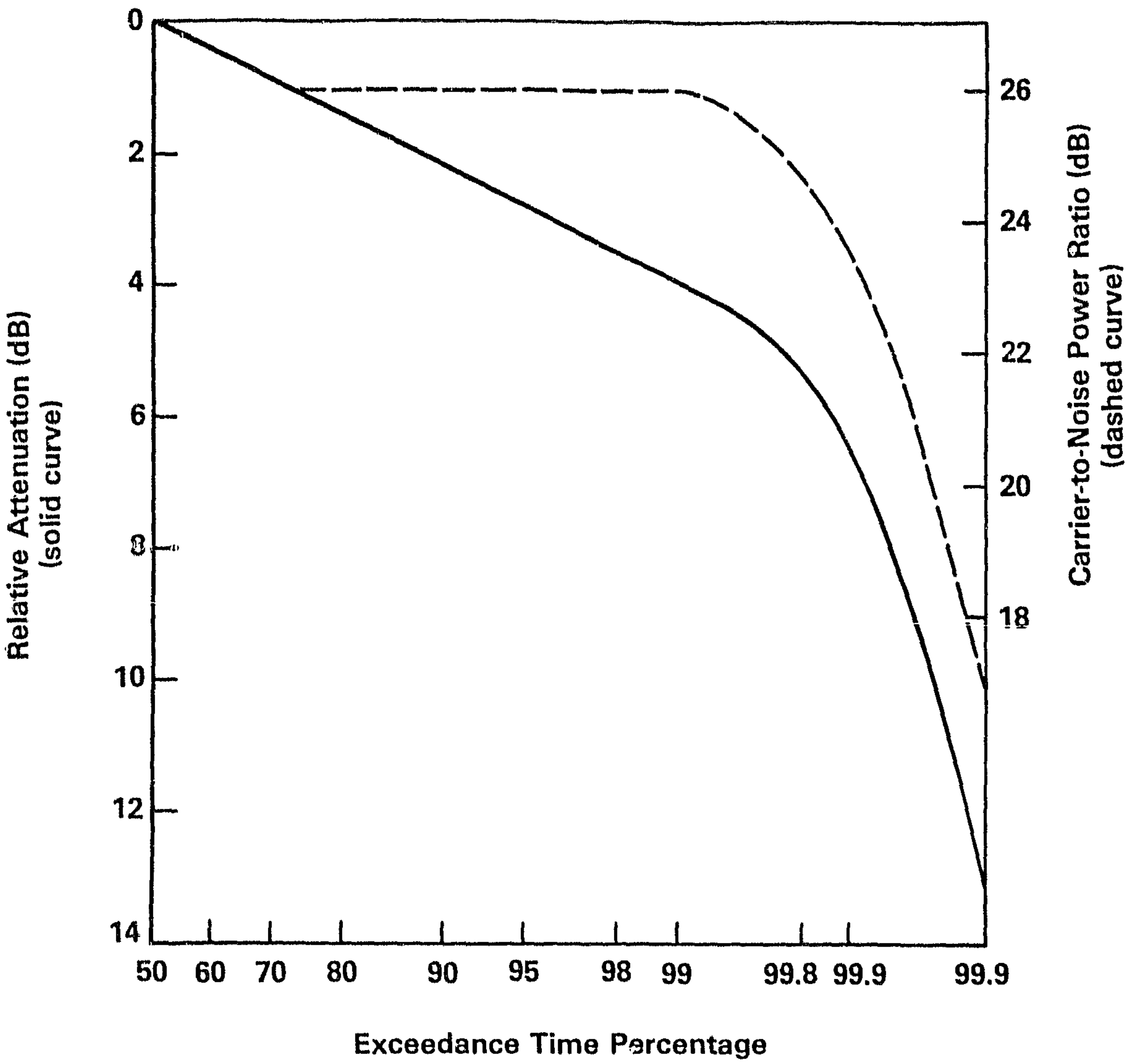

FIGURE A.2. HYPOTHETICAL CUMMULATIVE DISTRIBUTION OF FEEDER LINK C/N AND RELATIVE ATTENUATION

(The difference in the mean carrier power C(50) and power control activation threshold is 1 dB. The maximum EIRP boost is 3 dB, which is realized for 1% of the time.)

quality for small time percentages. For example, feeder link C/Ns of 24 dB exceeded for 99 percent of the time and 20 dB exceeded for 99.9 percent of the time might enable excellent and acceptable television reception for at least 99 and 99.9 percent of the time, respectively. This of course would assume no more than a specified level of interference. The criteria used in this analysis is a C/N of 26 dB exceeded for at least 99 percent of the worst-month.[15]

DETERMINATION OF CARRIER-TO-INTERFERENCE POWER RATIOS

All factors pertinent to the determination of the wanted carrier power level C and the interference power level I (single entry) have been presented. The problem at hand is to determine carrier-to-interference power ratios (C/Is) for the assessments of power control and choice of polarization for feeder links. The C/I at a satellite that is exceeded for a given percentage of time is dependent on the correlation between the C and I. Two general cases are considered in the analytical approach: high correlation and low correlation between C and I.

The case of high correlation between C and I occurs only when the desired and interfering feeder earth stations are nominally co-located. The limits on separations between earth-stations within which the high correlation case is applicable is dependent on radiometeorological parameters. General limits are determined in the consideration of the high correlation case.

The case of low correlation between C and I is generally encountered in BSS planning. This case occurs when the radiometeorological conditions on the C propagation path are essentially independent of those on the I path. This then implies independence between C and I.

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[15]United States (CCIR) Study Group BC, Elements of Feeder Link Planning, Doc. USSG-BC/402 (Rev. 2), (Draft US contribution to CCIR CPM), Washington, D.C., 5 April 1982.

Correlation Between C and I

A considerable amount of theoretical and measurement results on diversity are applicable to the determination of whether a high or low correlation could exist between C and I. A first-order criterion for high correlation would be the separation distance between the desired and interfering earth stations. When this distance is very small, the radiometorological conditions might be expected to be the same on the I and C paths (e.g., for separations of less than about 2 km). For moderate separation distances, (e.g., 2 km to about 15 km), the correlation of C and I becomes more strongly dependent on the I and C slant path orientations. When the earth stations are well separated (e.g., by more than 15 km), there will be little correlation between C and I in most cases.

The precise degree of correlation between C and I is dependent on the spatial characteristics of attenuating and depolarizing media such as rain. These spatial characteristics are statistical in nature. The orientation of the line connecting the desired and interfering earth stations is also influential, since there are seasonal line-of-motion trends for attenuating and depolarizing media. However, this latter factor has been found to have a weak influence on earth-to-space diversity gain.[16] Hence, the criterion for correlation need not consider this factor.

A simple criterion for correlation between C and I is used in this analysis. The criterion is dependent only on the separation distance between earth stations and is independent of climate, time percentage, C and I path orientations and other factors. The threshold between the high and low correlation cases is an earth station separation distance of 8 km. This is based on measurements of diversity gain made in New Jersey and Ohio, where it was found that the diversity gain is essentially independent of earth station separations greater than 8 km.[17] This result implies that the

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[16] Hodge, D.B., "Path Diversity for Earth-Space Communications Links," Radio Science, Vol. 13, No. 3, June 1978.

[17] Hodge, D.B., "Path Diversity for Reception of Satellite Signals," Journal De Recheraches Atmospheriques, Vol. 8, No. 5 1 and 2, January-June 1974.

radiometeorological conditions are independent on paths to the same satellite from sites separated by more than about 8 km in the areas where measurements were conducted.

High Correlation Case

The high correlation case considers that the same radiometeorological conditions exist on the C and I paths almost simultaneously. There is, however, a time during which the radiometeorological conditions will be somewhat different. This is true even with separations of less than about 2 km between the desired and interfering earth station. This analysis assumes that such time periods are negligibly small (i.e., <<1 percent of the worst-month).

Given that radiometeorological conditions on the C and I paths are equivalent, the C/I may be determined as shown in the following equation. For desired and victim earth stations having highly correlated radiometeorological conditions:

$$\frac{C}{I}(p) \simeq C(p) - I(p) \qquad (3)$$

where:

$\frac{C}{I}(p)$ = carrier-to-interference power ratio (dB) from a single interference entry, exceeded for p percent of the worst-month;

$C(p)$ = carrier power level (dBW) exceeded for p percent of the worst-month;

$I(p)$ = interference power level (dBW) exceeded for p percent of the worst-month.

Equation 3 can be used as specified only when interference decreases at a lower rate than the desired signal, as p is increased. Otherwise, the complementary definition for p would be used with Equation 3 and C/I (p), for p >90%, would be approximately that from clear-sky conditions on the C and I paths. For example, if the desired signal path elevation angle exceeds that of the interfering signal path and no power control is used, the I decreases more rapidly than C with increasing p and the complementary definition of p must be used: p is the percentage of the worst-month during which C/I (p) is not exceeded.

Low Correlation Case

Radiometeorological conditions on the C and I paths are assumed to be independent in the low correlation case. The probability of having a significant C reduction while I is simultaneously increased is negligibly small. For example, if C is significantly attenuated for 1 percent of the worst-month and the interfering signal significantly increased by depolarization for 2 percent of that worst-month, then the probability of these events occuring simultaneously is only 0.0002 (0.02 percent of the worst-month). If there are five such interferers, all of which are independent, the probability increases to only about 0.001 (0.1 percent of the worst-month). Thus, for desired and victim earth stations having low correlation between radiometeorological conditions:

$$\frac{C}{I}(p) = \begin{cases} C(90)-I(q), & \text{for } I(q)-I(10) \gg C(90)-C(p) \quad (4) \\ C(90)-I(q')=C(p')-I(10), & \text{for } I(q)-I(10) \approx C(90)-C(p) \quad (5) \\ C(p)-I(10), & \text{for } I(q)-I(10) \ll C(90)-C(p) \quad (6) \end{cases}$$

where:

C(90),I(10) = carrier and interference power levels (dBW) exceeded for 90 percent and 10 percent of the worst-month;

I(q) = interference power level (dBW) exceeded for q percent of the worst-month;

q = short-term worst-month time percentage during which interference may be enhanced, $q = 100-p$;

p',q' = exceedance time percentages for desired and interfering signals during which the C/I is determined from both desired signal fading and interference enhancement ($p'>90$, $q'<10$, $p = p'-q'$).

all other terms have been previously defined.

The C/I is determined from Equation 4 when the increase in interference greatly exceeds the desired signal attenuation. The opposite situation is treated in Equation 6. When the desired signal attenuations and interference increases both make significant contributions to the C/I (at different time periods), Equation 5 is used as illustrated in Figure A.3. These Equations are approximate since no account is taken of the probability of simultaneous interference enhancement and desired signal attenuation. However, this probability is negligibly small.

Multiple Entries of Interference

The power control and polarization analyses consider only single entry interference, but the multiple entry problem merits some attention. Each entry of interference will contribute a C/I component that can be determined from Equation 3, 4, 5 or 6, as appropriate. These can be combined to yield a multiple entry C/I exceeded for p percent of the worst-month, where the C is a constant for the specified value of p and the Is are cumulative. The following equation gives the net C/I.[18]

$$\frac{C}{I}(p)_T = -10 \log \sum_i 10^{-0.1\left(\frac{C}{I}(p)_i\right)} \tag{7}$$

where:

$\frac{C}{I}(p)_T$ = net C/I exceeded for p percent of the worst-month;

i = ith interference entry;

$\frac{C}{I}(p)_i$ = C/I exceeded for p percent of the worst-month resulting from the ith interferer, (p = 50 for all but worst interferer).

[18] Davidson, J., Sawitz, P., Spectrum/Orbit Utlization Program Users Manual, Final Draft-Volume 1, prepared by ORI under contract NAS3-22885, NASA Lewis Research Center, Cleveland, Ohio, 9 September 1981.

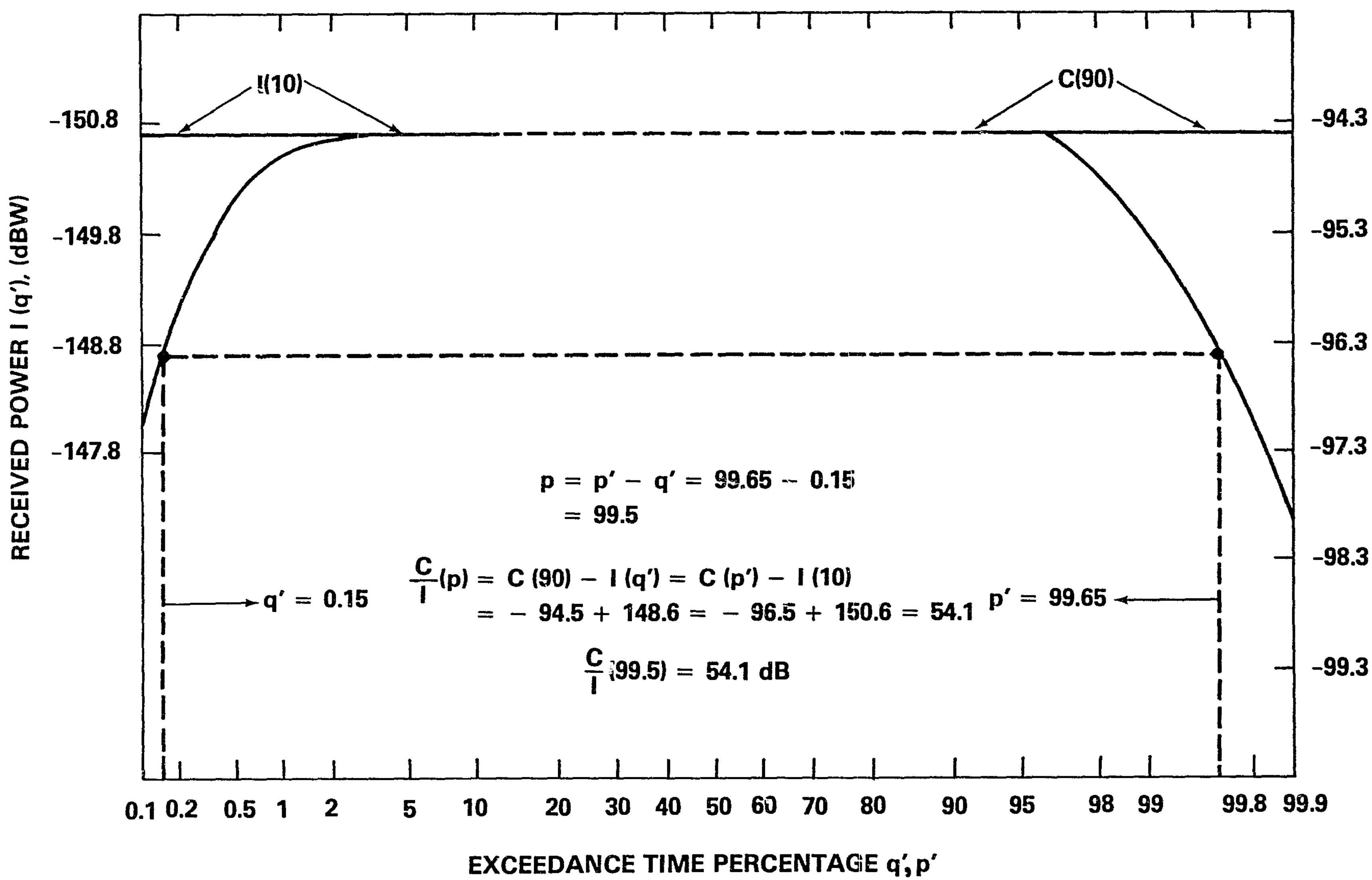

Figure A.3. Example Determination of C/I(p) When Both the Desired and Interfering Signal Variabilities are Significant.

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POWER CONTROL ANALYSIS APPROACH

The statistical analysis of power control (Section II) can be accomplished through an examination of C/Is exceeded for 90 percent, 95 percent, 99 percent, 99.5 percent and 99.9 percent of the worst-month since these conditions delimit short-term feeder link degradation. The Cs and Is are individually determined using the methods presented earlier in this Appendix for the various cases of power control implementation in the desired and interfering feeder links. Equations 4, 5 and 6 are then used to determine the appropriate C/Is since the C and I may be assumed to be uncorrelated in the context of international planning. These steps are delineated below. Circular polarization is assumed for all feeder links. The co-polarized antenna patterns that were used were the CCIR Fixed-Satellite service earth station and WARC-77 12 GHz satellite patterns. The cross-polarized antenna patterns that were used were the CPM earth station and WARC-77 12 GHz satellite patterns.

Determination of Carrier Power Levels

The (wanted) carrier power levels at the spacecraft transponder input are first determined for the case of a fixed-EIRP (no power control) earth station. The received carrier power level is assumed to be -95.3 dBW for 99 percent of the worst-month based on the 26 dB C/N requirement, the availability objective, and an assumed 2000°K noise temperature in a 27 MHz bandwidth. This then enables the sizing of earth station EIRP and subsequent determination of carrier power levels for other time percentages. This is accomplished by executing the Spectrum Orbit Utilization Program (SOUP)[19] to determine all link parameters and incorporating the appropriate water vapor or rain attenuation variabilities. The received carrier powers exceeded for 50 percent, 90 percent, 99 percent, 99.5 percent and 99.9 percent are calculated for all fixed-EIRP links for use in Equations 4, 5 and 6.

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[19] Ibid.

*Unlimited power control is a trivial case, wherein the received carrier power level is at a constant -95.3 dBW for time percentages greater than 90 percent.

The effect of power control with 5 dB, 10 dB, 15 dB and unlimited dynamic ranges will depend on the implementation scheme. It is assumed that power control will result in a wanted carrier power level of -95.3 dBW for at least 99 percent of the worst-month, thereby fulfilling C/N availability requirements. At the same time it may be desired to limit the power control activation period to be no more than about 10 percent of the worst-month (i.e., about 4 percent of the average year). These conditions establish criteria for selecting the baseline EIRP (power control not activiated) given the power control dynamic range. The baseline EIRPs are determined as follows:

1. The baseline EIRPs are those that provide 90 percent availability (power control not activated).

2. In cases where the dynamic range of power control is insufficient to enable the required availability, the baseline EIRP is increased until the maximum EIRP (baseline EIRP plus dynamic range) provides the required availability.

The above approach enables the attainment of higher than-specified availability when excessively high power control dynamic ranges are utilized (e.g., unlimited dynamic range). The received carrier power levels are determined for 90 percent, 95 percent, 99 percent, 99.5 percent 99.9 percent of the worst-month for the cases of 0 dB, 5 dB, 10 dB, 15 dB and unlimited* power control dyanmic range.

Determination of Interference Power Levels

The statistical on-axis EIRP levels of an interfering earth station will have been established in the previous analysis of the received power levels of the desired carrier. The power levels (Is) due an interfering earth station can readily be determined using interference path parameters generated by the SOUP, the statistical variation of attenuation on the interfering signal path, and the equivalent gain method for treating XPD in Appendix B. Co-polarized and cross-polarized feeder links are considered since both might be encountered in the BSS planning.

POLARIZATION ANALYSIS APPROACH

The performance of orthogonal linearly and circularly polarized feeder links for the special case of nominally co-located satellites can be assessed in relative terms. The performance of orthogonal linearly polarized links during depolarization events as compared to that of orthogonal circularly polarized links is of particular concern. The following approach has been used to accomplish this comparison, the results of which are contained in Section III.

1. The statistical XPDs which include ice and rain depolarization were determined for selected geometries and rain climates found in the continental United States, using the method in Appendix B.

2. The statistical equivalent antenna gains on interference paths between feeder links to nominally co-located satellites were determined. The approach of Appendix B was used for satellite separations of 0.1°, 0.3° and 0.5°. The CPM earth and space station antenna patterns for feeder links were used.[20]

3. The differences between the statistical equivalent antenna gains on interference paths between orthogonal-circular and between orthogonal-linear feeder links were determined. These values are the maximum potential differences in C/Is between orthogonal linearly and circularly polarized feeder links - the desired results.

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[20] CCIR, Technical Bases for the Regional Administrative Radio Conference 1983 for the Planning of the Broadcasting-Satellite Service in Region 2, Geneva, Switzerland, 1982.

APPENDIX B

CHARACTERIZATION OF DEPOLARIZATION EFFECTS

INTRODUCTION

The effects of depolarization of signals on a given path are generally quantified as a reduction in XPD. The reduction in XPD can give rise to a significant change in the equivalent combined gain of the transmitting and receiving antennas. This equivalent gain is the effective sum of transmitting and receiving antenna gains that is corrected for polarization mismatch and antenna characteristics. A method for determining equivalent gain is presented in this Appendix together with a method for determining ice cloud and rain induced XPD reductions.

EQUIVALENT GAIN

The equivalent gain can be determined from the following approximate equations[1].

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[1]Equivalent Gain for Each Partial Link, prepared by Canadian participants in the ITU Panel of Experts preparations for the 1983 Broadcasting-Satellite WARC (for incorporation in the WARC orbit/spectrum plan analysis computer program), received from K. Brown (Canada) on 20 January 1982.

[1]CCIR, Technical Bases for the Regional Administrative Radio Conference 1983 for the Planning of the Broadcasting-Satellite Service in Region 2, Geneva, Switzerland, 1982.

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$$G = G_1 \cos^2 \beta + G_2 \sin^2 \beta \qquad (1)$$

$$G_1 = G_{tp} G_{rp} + G_{tc} G_{rc} + G_{tp} G_{rc}X + G_{tc} G_{rp}X \qquad (2)$$

$$G_2 = \left| \sqrt{G_{tp} G_{rc}} + \sqrt{G_{tc} G_{rp}} \right|^2 + G_{tp} G_{rp}X + G_{tc} G_{rc}X \qquad (3)$$

where:

G = equivalent gain (numerical);

β = relative alignment angle between transmitting and receiving antenna polarization planes;

G_{tp}, G_{rp} = transmitting and receiving co-polar gains (numerical), respectively;

G_{tc}, G_{rc} = transmitting and receiving cross-polar gains (numerical), respectively;

X = reciprical of the cross-polarization discrimination (numerical power ratio, $X < 1.0$), $X = \exp(-XPD/10)$

The approximations in Equations 1, 2, and 3 are due to the assumptions regarding phase alignment and the consequential voltage and power summations of gain terms. It is felt that the above method represents a reasonable compromise between accuracy and simplicity.

For circular polarization, the angle β is 0^o for co-polar transmission and reception, and 90^o for the cross-polar case. For the case of linear polarization for transmission and reception, 0^o and 90^o will be used for co-polar and cross-polar cases. These β values are ideal, since the polarization plane orientation generally changes at off-axis angles and other factors such as satellite yaw motion are not taken into account.

Nominal values will be used for the satellite and earth station co-polar and cross-polar main beam gains. The difference in co-polar and cross-polar gains is of greatest importance, as opposed to their precise

values. The difference in these gains is largely established by antenna feed components, and may differ appreciably between antennas using circular and linear polarization.[2] Values for these gains will be representative of practicable antenna designs. This is essential for the evaluation of the relative merits of linear and circular polarization for the special case of sharing between feeder links to co-located satellites having overlapping service areas.

The best available representative reference radiation patterns will be used for the calculation of equivalent gain in the general case where feeder link service areas do not overlap. The WARC-77 satellite antenna patterns for transmission at 12 GHz may be representative of readily achievable characteristics for reception at 17.5 GHz. Cross-polar reference patterns for fixed earth stations at 17.5 GHz are not generally available.

REDUCTIONS IN XPD DUE TO DEPOLARIZATION

A formidable number of measurements have been made of rain-induced depolarization. Depolarization due to ice crystals has been measured and documented to a lesser extent. The CCIR quasi-empirical XPD equations for depolarization provide a convenient means for determining rain-induced XPD reductions.[3] It has been suggested that ice-crystal depolarization effects

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[2] CCIR, "Discrimination by means of Orthogonal Linear and Circular Polarizations," Propagation in Non-Ionized Media, Report 555-1, Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

[3] CCIR, Cross Polarization Due to the Atmosphere, Report 722 (MOD F), Doc. 5/5005, Geneva, Switzerland, 7 September 1981.

can be incorporated through the addition of a constant, but this approach must be used with caution.[4] In some climates, ice-induced depolarization may be dominant for percentages of time greater than 0.1 percent.[5] The following CCIR method for predicting median values values of XPD will be used.[6]

$$XPD = U - Ki - V \log (CPA) \tag{4}$$

$$U = K^2 - 10 \log ½ \left|1 - \cos (4\tau)e^{-Km^2}\right| + 30 \log f - 40 \log (\cos \epsilon) \tag{5}$$

Where:

XPD = cross-polarization discrimination (dB);
CPA = co-polar rain attenuation (dB);
Ki = allowance for ice-induce depolarization (dB);
V = constant, equal to about 23 dB for $15 < f < 35$ GHz;
K,Km = effective parameters of the raindrop canting angle distribution ($dB^{1/2}$, degrees);
τ = polarization tilt angle (degrees) with respect to horizontal;
f = frequency (GHz);
ϵ = slant path elevation angle (degrees).

The factor Ki; in the Equation 4 is the best available means for incorporating ice-induced depolarization effects. This approach directly relates the statistics of ice-induced depolarization effects to those of rain. This appears to be intuitively correct for certain conditions, where the variabilities of ice and rain depolarization effects are similar.

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[4]Chu, T.S., "Analysis and Prediction of Cross-Polarization on Earth-Space Links," Proceedings of URSI Commission F, International Symposium at Lennoxville, Canada (preprint of papers by University of Bradford, UK), May 1980.

[5]CCIR, Propagation Data for Broadcasting from Satellites, Report 565-1 (MOD F), Doc. 5/5041, Geneva, Switzerland, 10 September 1981.

[6]CCIR, Propagation Data Required for Space Telecommunication Systems, Report 564-1 (MOD F), Doc. 5/1044, Geneva, Switzerland, 28 September 1981.

However, this approach could be unreliable for large time percentages (e.g., 1.0 percent) where there may be little relation between the presence of ice crystals and rain. An allowance of 2 dB has been found to be appropriate for much of North America, and 4 or 5 dB for the maritime climate of north western Europe.[7] Application of these values to analogous Region 2 climates yields the following provisional allowances:

Climates A, B, C, K : 2 dB allowance;
Climates D, E, F, N, P: 4 dB allowance;
Climates G, M : 5 dB allowance.

Values of 0 and 0.24 for K and K_m, respectively, characterize a conservative raindrop canting angle distribution for the purposes of comparing linear and circular polarization effects.[8] Values for the parameter τ will be 0^0 and 90^0 for horizontal and vertical linear polarizations, and 45^0 for circular polarizations.

APPLICATIONS IN C/I CALCULATIONS

The effect of depolarization need not be considered in calculating the wanted carrier power level, as was noted in the text, since the equivalent gain will show little variation. This is due to the fact that the equivalent gain is largely determined by the co-polar antenna gains in this case. This is not the case for nominally cross-polarized interfering emissions, where the cross-polar gain components become more significant. Accordingly, depolarization effects will be considered in only the interference calculations.

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[7] Ibid.

[8] Ibid.

APPENDIX C
PRECIPITATION SCATTER EFFECTS ON FEEDER LINK POWER CONTROL AND SHARING NEAR 17.5 GHz

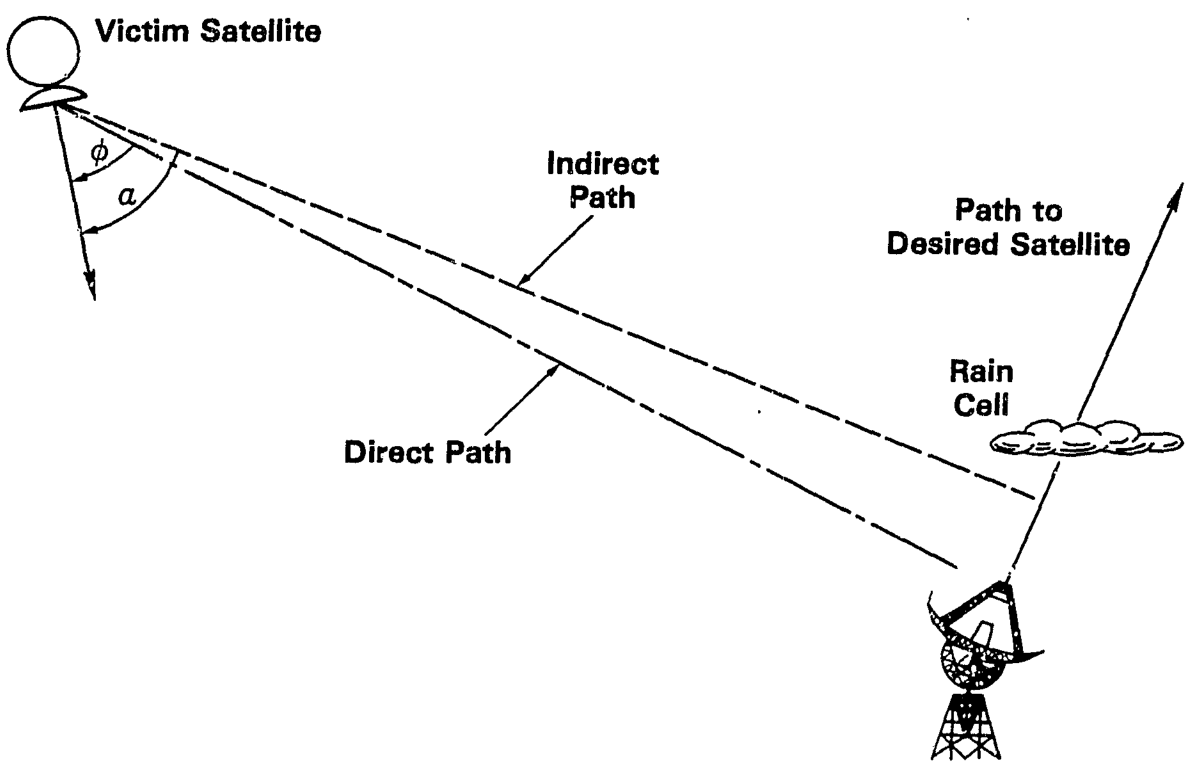
INTRODUCTION

The propagation of interfering emissions through the precipitation scatter mechanism has been found to be significant in frequency sharing between earth stations and terrestrial stations. Rain is generally taken to be the predominant scattering medium, although clouds, ice crystals, hail, and snow can also produce scattering. This Appendix shows that rain scatter can possibly contribute interference between feeder links at 17.5 GHz but that these levels of interference will be insignificant. It is shown that the rain scatter interference component and that from the direct path might, during certain rain conditions, combine to yield a higher net interference level at a geostationary satellite than is present during clear sky conditions. However, it must be borne in mind that a provisional adaptation of a rain scatter model for interference between ground-based stations has been made and that further study is required. All assumptions that may affect the validity of this adaptation are stated.

The approach herein is to predict the level of indirect path interference (rain scatter) relative to that of the direct path. These interference paths are illustrated in Figure C.1. Primary consideration is given to the case where essentially the same rain conditions are present on the direct and indirect paths, since this condition can be expected during

much of a rain event. The case where the rain rates are appreciably different on the two paths is treated less rigorously. A means for predicting the total interference is embodied in the calculations. Finally, to facilitate the study of this phenomenon in the context of power control, a criterion is developed for use in estimating a maximum permissible level of power boost that takes the direct plus indirect path interference into account.

FIGURE C.1 Illustration of Rain Scatter Geometry



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RELATIVE DIRECT AND INDIRECT PATH INTERFERENCE LEVELS

The ratio of direct path to indirect path interference power is a useful parameter for assessing the significance of rain scatter. Large values of this ratio (e.g., 20 dB) indicate that the rain scatter interference is negligible in relation to the direct path interference for the radio-meteorological and geometrical conditions under consideration. The following equations can be used to determine approximate values for this ratio.

$$P_{RD} = P_t + G_t(\Theta) + G_r(\phi) - L_{fs} - L_r - L_a \tag{1}$$

$$P_{RI} = P_t - L_{rs} \tag{2}$$

$$P_{RD} - P_{RI} = G_t(\Theta) + G_r(\phi) - L_{fs} - L_r - L_a + L_{rs} \tag{3}$$

where:

P_{RD}, P_{RI} = received interference power (dBW) from emissions propagating over direct and indirect paths, respectively;

$G_t(\Theta)$ = interfering earth station antenna gain (dBi) at off-axis angle Θ toward the victim satellite;

$G_r(\phi)$ = satellite receiving antenna gain (dBi) toward interfering earth station;

L_{fs} = basic transmission loss (dB) on direct path;

L_a = gaseous attenuation (dB) on direct path;

L_r = rain attenuation (dB) on direct path;

P_t = transmitter power (dBW) at the input to the interfering earth station antenna;

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L_{rs} = transmission loss (dB) on the rain scatter path.

The approximation in the above equations arises from the omission of antenna polarization characteristics and rain depolarization effects. These factors could significantly affect the levels of interference power on both the direct and indirect paths.

Substitutions can be made for the propagation loss terms in Equation 3 terms using quasi-empirical equations for rain scatter loss between ground-based stations,[1] free space loss, and rain attenuation.[2] These substitutions as well as a number of simplifying assumptions result in the following equations:

$$L_{rs} = 199 + 20 \log d_i - 20 \log F - 10 \log Z - G_r(\alpha) + 10 \log A - 10 \log C - 10 \log D + L_i \quad (4)$$

$$L_{fs} = 92.45 + 20 \log F + 20 \log d_d \quad (5)$$

$$L_r = \gamma L_{sd} r_{pd} \quad (6)$$

$$P_{RD} - P_{RI} = G_t(\Theta) + 106.55 - 40 \log F - \gamma L_{sd} r_{pd} + 10 \log A - 10 \log C - 10 \log D - 10 \log Z \quad (7)$$

where:

F = frequency (GHz);
γ = specific attenuation (dB/km) for rain on direct path;

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[1]CCIR, "The Evaluation of Propagation Factors in Interference Problems at Frequencies Greater than 0.6 GHz," Propagation in Non-Ionized Media, (Report 569-1), Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

[2]CCIR, Propagation Data Required for Space Telecommunication Systems, Report 564-1 (MOD F), Doc. 5/1044, Geneva, Switzerland, 28 September 1981.

d_i = distance between victim satellite and rain cell (Km);

d_d = distance between victim satellite and interfering earth station (Km);

$G_r(\alpha)$ = satellite receiving antenna gain (dBi) toward rain cell;

L_i = gaseous attenuation on the indirect path (dB);

L_{sd} = slant path distance (km) below 0^0 C isotherm;

r_{pd} = reduction factor;

10 log A = allowance for deviation from Rayleigh scattering (dB);

10 log C = attenuation (dB) due to rain on rain scatter path;

D = effective dimension of rain volume (km) for scatter;

Z = reflectivity factor (mm^6/m^3).

Several assumptions are implied in Equation 7: The space station antenna gains towards the direct and indirect paths are assumed to be the same ($G_r(\phi)$, $G_r(\alpha)$), since the off-axis angles (ϕ and α) toward both paths are essentially equal. The distances between the earth station and satellite and rain cell and satellite are assumed equal ($d_d \simeq d_i$). The gaseous attenuations on the direct and indirect paths are assumed to be equal ($L_a \simeq L_i$). These assumptions have a negligible effect on the direct-to-indirect path interference power ratio.

The allowance for deviation from Rayleigh scattering (10 log A), as determined by the CCIR method, is a function of rain rate, frequency, and relative azimuth angle between the earth station and terrestrial station main beams (scattering angle) for the case of earth station/terrestrial station interactions. The topocentric angle between desired and victim satellites is

used as the scattering angle. This approach is directly applicable to feeder link sharing only for the case of victim satellites near the rain cell horizon, where the path geometry is similar to the earth station/terrestrial station case. This would introduce the greatest error for high direct path elevation angles, but this error should be negligible (<<1 dB).

The attenuation due to rain on the indirect path below the 0^{o} C isotherm (10 log C) is a function of the specific attenuation, the effective dimension of the rain volume along the earth station main beam, and the scattering angle. The specific attenuation and effective dimension can be determined using CCIR methods.[3]

The effective dimension of the rain volume for scattering (D) is the effective projection of the satellite antenna beam cross-section on the earth station main beam effective slant path through rain. The satellite antenna gain toward any point in the scattering volume is essentially constant, so it can be assumed that the effective dimension for scattering is equal to the effective slant path dimension of the earth station main beam below the 0^{o} C isotherm. This does not introduce any geometric error, even for the case of the narrowest possible satellite antenna beam (e.g., 0.6^{o}) directed towards the scattering volume. However, it is assumed that no scattering takes place above the 0^{o} C isotherm, which will tend to underestimate the level of the indirect path interference component. (This latter factor is further considered below.)

The reflectivity factor (Z) can be determined from the vertical reflectivity profile for a given time percentage and climatic zone. This factor must complement the effective dimension for scatter (D). The analytical approach herein uses a power law function of rain rate with a constant reflectivity from the ground to the 0^{o} C isotherm, with zero reflectivity above that height. Some scattering will typically take place above the 0^{o} C isotherm, particularly in the melting layer. The enhanced scattering that can take place in the melting layer is negligible in sharing between ground-based stations since this region is a small portion of the

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[3] Ibid.

overall scattering dimension.[4] This may not be the case in some geometriesassociated with feeder link sharing. Reflectivity above the melting layer decreases at a rate of about 2 dB/km through ice clouds and 7 dB/km above.[5] The use of constant reflectivity up to the 0^{o} C isotherm height is justified by measured and theoretical vertical reflectivity profiles.[6] The treatment of reflectivity in the above manner results in a general underestimation of the rain scatter interference power component. It should be noted that ice clouds exhibit reflectivities as high as 100 mm^6/m^3 in the absence of rain with little appreciable attenuation for up to about 10 percent of the time, depending on climate.[6] This indicates that scatter could occur for much larger time percentages for earth-to-space paths than is predicted by rain scatter considerations alone, but the magnitude of these scattered emissions might be relatively low at 17.5 GHz.

The earth station antenna gain $G_t(\theta)$ can be estimated from the reference pattern in Appendix 29 of the ITU Radio Regulations. This reference pattern is a nominal envelope of most of the sidelobe gain peaks for electrically large antennas and is generally accepted for use in interference analyses for fixed earth stations. The results of all direct path calculations are predicated on this pattern.

The overall confidence in the above calculation approach is unknown due to the forementioned assumptions. There is considerable uncertainty in the applicability of the CCIR rain scatter model to feeder link sharing, since this quasi-empirical model is based on bistatic radar measurements and observations made only in the vicinity of the rain cell azimuthal plane (e.g., a plane tangent to the surface of the earth). The confidence is greatest for satellites near the rain cell horizon, which corresponds with the explicit geometry in the CCIR rain scatter model.

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[4] CCIR, "Propagation Data for the Evaluation of Coordination Distance in the Frequency Range 1 to 40 GHz," Propagation in Non-Ionized Media, (Report 724), Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

[5] CCIR, "Radiometeorological Data," Propagation in Non-Ionized Media, (Report 563-1), Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

[6] Ibid.

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ANALYTICAL RESULTS

Equation 7 was solved for various radiometeorological and geometric conditions using the latest CCIR rain climate data.[7] The case where rain conditions are similar on the direct and indirect paths is presented first. The case of differing rain rates on the two paths is then treated.

The resulting ratios of direct-to-indirect path interference power are presented in all cases. The rain attenuations are also presented as they are needed for the assessment of power control. Finally, an interference "margin" is presented which gives the ratio of clear sky interference-to-total net interference during rain, as described in Equation 8 below. If the maximum permissible EIRP boost is that which produces no more than the clear sky level of interference, the boost can be no greater than this margin. A negative margin implies that EIRP must be lowered to produce no more than the clear sky level of interference. The direct and indirect path interference components are assumed to be power additive in Equation 8.

$$M = L_r - 10 \log \left[1 + 10^{-(P_{RD} - P_{RI})/10} \right] \qquad (8)$$

where:

M = margin of interference between clear sky and rain conditions (dB), (ratio of clear sky interference to total interference during rain from one earth station);

all other terms have been previously defined.

Similar Rain Conditions on Both Paths

Similar rain rates can be expected on the direct and indirect paths during most of a rain event. A discussion of the likelihood of having differing rain rates on the two paths is contained in the next section of this Appendix.

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[7] CCIR, Radiometeorological Data, Report 563-1 (MOD F), Doc. 5/5049, Geneva, Switzerland, 10 September, 1981.

The effects of varying radiometeorological conditions are considered first. The effects of various geometries, as pertaining to different earth station and victim and desired satellite positions, are then considered.

Rain attenuations, direct-to-indirect interference power ratios, and interference margins for the rain rates and 0^{o} C isotherm heights corresponding to four average-yearly time percentages are tabulated in Table C.1. Worst-month time percentages are also noted, these having been determined using a nominal climate-independent average-yearly to worst-month conversion.[8] A fixed geometry that accentuates the relative rain scatter interference was used. The earth station is located at the equator with direct and indirect path elevation angles of 20^{o} and a topocentric victim-to-desired satellite separation of 138^{o}. Results for most rain climate zones in Region 2 are shown, although these do not all exist at the equator. Since the direct and indirect path elevation angles are equal, the rain attenuations on the direct path and the desired signal paths are equal.

Table C.1 shows that indirect path interference can greatly exceed that from the direct path for the given geometry. This is attributable to the low direct path antenna gain and elevation angle and correspondingly high rain loss on the direct path, as shown in the results. For a given rain zone, the margins can be seen to decrease with increasing percentage of time (i.e., decreasing rain rate). It is interesting to note that the net interference can be almost as large as the clear sky level, as is evident in the near-zero margins for rain conditions associated with larger time percentages. However, the clear sky interference for the given geometry is expected to be extremely low.

Tables C.2, C.3, and C.4 show the effects of varying the earth station antenna elevation angle and orbit spacing between the victim and desired satellite. A number of earth station latitudes and rain climate zones corresponding to representative Region 2 feeder link situations are considered. The direct path elevation angle was fixed at a low value, thereby yielding results for the case of a victim satellite near the earth station horizon. Tables C.2, C.3, and C.4 give results for 0.01, 0.1, and 1.0 percent

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[8]CCIR, <u>Worst-Month Statistics</u>, Report 723 (MOD F), Doc. 5/5028, Geneva, Switzerland, 9 September 1981.

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TABLE C.1

EFFECTS OF VARYING RADIOMETEOROLOGICAL PARAMETER VALUES ON RAIN SCATTER INTERFERENCE - SAME RAIN RATE AND HEIGHT ON BOTH PATHS

DATA FOR 0.001% OF THE YEAR (0.0072% OF THE WORST MONTH)

RAIN ZONE	RATE (mm/h)	HEIGHT OF $0^{o}C$ ISOTHERM (km)	$P_{RD}-P_{RI}$ (dB)	RAIN LOSS ON DIRECT PATH	MARGIN (dB)
A	22	5.33	-9.2	11.4	1.8
B	32	5.33	-15.0	17.4	2.3
C	42	5.33	-20.9	23.7	2.8
D	42	5.33	-20.9	23.7	2.8
E	70	5.33	-37.7	42.1	4.4
G	65	5.33	-34.6	38.7	4.1
K	100	5.33	-56.4	62.9	6.5
M	120	5.33	-69.1	77.2	8.1
N	180	5.33	-108.6	121.8	13.2
P	250	5.33	-156.5	176.2	19.7

DATA FOR 0.01% OF THE YEAR (0.053% OF THE WORST MONTH)

RAIN ZONE	RATE (mm/h)	HEIGHT OF $0^{o}C$ ISOTHERM (km)	$P_{RD}-P_{RI}$ (dB)	RAIN LOSS ON DIRECT PATH	MARGIN (dB)
A	8	5.06	-2.0	5.3	1.2
B	12	5.06	-5.6	8.4	1.7
C	15	5.06	-8.1	10.8	2.0
D	19	5.06	-11.4	14.0	2.3
E	22	5.06	-13.8	16.5	2.6
G	30	5.06	-20.3	23.5	3.1
K	42	5.06	-30.3	34.3	4.0
M	63	5.06	-48.2	54.0	5.9
N	95	5.06	-76.5	85.8	9.3
P	145	5.06	-122.7	138.1	15.3

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TABLE C.1 (Cont)

EFFECTS OF VARYING RADIOMETEOROLOGICAL PARAMETER VALUES ON RAIN SCATTER INTERFERENCE - SAME RAIN RATE AND HEIGHT ON BOTH PATHS

DATA FOR 0.1% OF THE YEAR (0.40% OF THE WORST MONTH)

RAIN ZONE	RATE (mm/h)	HEIGHT OF 0^oC ISOTHERM (km)	$P_{RD}-P_{RI}$ (dB)	RAIN LOSS ON DIRECT PATH	MARGIN (dB)
A	2	4.83	5.5	1.6	0.5
B	3	4.83	3.0	2.5	0.8
C	5	4.83	-0.5	4.5	1.2
D	8	4.83	-4.4	7.6	1.8
E	6	4.83	-1.9	5.5	1.4
G	12	4.83	-9.1	12.0	2.4
K	12	4.83	-9.1	12.0	2.4
M	22	4.83	-20.3	23.8	3.4
N	35	4.83	-35.3	40.1	4.8
P	65	4.83	-71.5	80.5	9.0

DATA FOR 1.0% OF THE YEAR (2.93% OF WORST MONTH)

RAIN ZONE	RATE (mm/h)	HEIGHT OF 0^oC ISOTHERM (km)	$P_{RD}-P_{RI}$ (dB)	RAIN LOSS ON DIRECT PATH	MARGIN (dB)
B	1	4.61	9.7	0.7	0.3
D	3	4.61	2.9	2.6	0.8
E	1	4.61	9.7	0.7	0.3
F	2	4.61	5.4	1.6	0.5
K	2	4.61	5.4	1.6	0.5
M	4	4.61	0.9	3.6	1.0
N	5	4.61	-0.7	4.6	1.3
P	12	4.61	-9.3	12.3	2.5

EXAMPLE: (Equation 7): Zone P, 1% of the Year

$$P_{RD} - P_{RI} = (G_t(\theta) = -10) + 106.55 - 40 \log (17.5) - (\gamma L_{sd} r_{pd} = 12.3) + (10 \log A = 0.4) - (10 \log C = -8.2) - (10 \log D = 11.3) - (dBZ = 41.1) = -9.3$$

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TABLE C.2

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION ANGLE
WITH A CONSTANT LOW DIRECT PATH ELEVATION ANGLE
(0.01% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	5/5.3	16.7	21.9	P	-15.0	131.3/136.7
0	15/16.0	16.7	32.7	P	-54.1	104.7/97.8
0	30/32.7	16.7	49.3	P	-84.9	84.4/66.9
0	40/44.1	16.7	60.8	P	-97.8	77.7/54.1
0	50/55.7	16.7	72.4	P	-105.6	74.7/46.2
0	60/67.4	16.7	84.1	P	-110.8	75.0/41.1
0	75/85.1	16.7	78.2	P	-119.9	74.5/32.0
0	85/96.8	16.7	66.5	P	-125.3	75.8/26.6
0	100/114.0	16.7	49.3	P	-131.6	84.4/20.3
0	115/130.6	16.7	32.7	P	-136.5	104.7/15.4
0	130/146.6	16.7	16.7	P	-140.8	151.9/11.1
0	5/5.3	16.7	21.9	N	-4.7	81.6/88.4
0	30/32.7	16.7	49.3	N	-54.6	52.4/39.8
0	50/55.7	16.7	72.4	N	-68.3	46.5/26.1
0	75/85.1	16.7	78.2	N	-76.2	46.3/18.2
0	100/114.0	16.7	49.3	N	-82.6	52.4/11.8
0	130/146.6	16.7	16.7	N	-87.5	94.4/6.9
20	5/5.2	15.0	19.9	M	1.9	54.5/60.9
20	20/21.4	15.0	34.5	M	-27.4	40.0/35.7
20	35/38.1	15.0	48.7	M	-40.8	33.5/22.3
20	50/55.3	15.0	61.0	M	-47.5	30.6/15.6
20	70/78.5	15.0	65.9	M	-51.3	30.0/11.8
20	85/95.8	15.0	57.3	M	-53.6	31.3/9.5
20	100/112.8	15.0	44.1	M	-55.3	35.1/7.8
20	115/129.9	15.0	29.6	M	-56.9	43.6/6.2
20	130/145.0	15.0	15.0	M	-57.9	63.1/51.5
20	5/5.2	15.0	19.9	N	-5.6	86.5/93.5
20	20/21.4	15.0	34.5	N	-44.1	63.5/56.0
20	35/38.1	15.0	48.7	N	-62.5	53.1/37.7
20	50/55.3	15.0	61.0	N	-72.4	48.6/27.7
20	70/78.5	15.0	65.9	N	-79.4	47.6/20.7
20	85/95.8	15.0	57.3	N	-83.7	49.6/16.5
20	100/112.8	15.0	44.1	N	-87.1	55.7/13.1
20	115/129.9	15.0	29.6	N	-90.0	69.2/10.1
20	130/145.0	15.0	15.0	N	-92.2	100.2/8.0

TABLE C.2 (Cont)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
20	5/5.2	15.0	19.9	E	14.2	16.7/19.2
20	20/21.4	15.0	34.5	E	-4.4	12.2/13.6
20	35/38.1	15.0	48.7	E	-12.1	10.2/7.0
20	50/55.3	15.0	61.0	E	-15.3	9.4/3.9
20	70/78.5	15.0	65.9	E	-15.9	9.2/3.3
20	85/95.8	15.0	57.3	E	-16.2	9.6/3.0
20	100/112.8	15.0	44.1	E	-16.5	10.7/2.8
20	115/129.9	15.0	29.6	E	-16.6	13.4/2.6
20	130/145.0	15.0	15.0	E	-16.7	19.3/2.5
20	5/5.2	15.0	19.9	C	17.4	10.8/12.5
20	20/21.4	15.0	34.5	C	0.4	8.0/9.7
20	35/38.1	15.0	48.7	C	-6.5	6.7/5.2
20	50/55.3	15.0	61.0	C	-9.3	6.1/2.8
20	70/78.5	15.0	65.9	C	-9.7	6.0/2.4
20	85/95.8	15.0	57.3	C	-9.9	6.2/2.3
20	100/112.8	15.0	44.1	C	-10.0	7.0/2.2
20	115/129.9	15.0	29.6	C	-10.0	8.7/2.1
20	130/145.0	15.0	15.0	C	-10.0	12.6/2.2
30	5/5.2	14.7	19.1	K	8.0	33.9/38.3
30	18/19.2	14.7	30.3	K	-13.3	26.0/25.5
30	38/41.3	14.7	45.6	K	-26.8	20.7/12.1
30	50/54.9	14.7	52.2	K	-30.2	19.4/8.8
30	68/75.5	14.7	54.6	K	-31.9	19.1/7.0
30	83/92.5	14.7	48.7	K	-33.0	20.1/6.0
30	98/109.3	14.7	38.4	K	-33.7	22.7/5.3
30	113/125.6	14.7	26.0	K	-34.3	28.4/4.7
30	123/136.1	14.7	17.4	K	-34.6	35.7/4.4
37.5	5/5.3	15.0	18.8	D	16.1	12.9/14.6
37.5	20/21.3	15.0	29.9	D	-1.0	9.8/11.1
37.5	35/37.8	15.0	39.3	D	-8.1	8.3/5.9
37.5	50/54.6	15.0	45.3	D	-11.2	7.6/3.2
37.5	65/71.6	15.0	46.2	D	-11.5	7.6/2.9
37.5	80/88.4	15.0	41.7	D	-11.7	8.0/2.7
37.5	95/104.9	15.0	33.2	D	-11.8	9.2/2.6
37.5	110/121.0	15.0	22.6	D	-11.8	11.6/2.6
37.5	120/131.4	15.0	15.0	D	-11.7	14.7/2.7

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TABLE C.2 (Cont)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.3	16.1	18.8	B	20.9	6.2/6.8
50	20/21.3	16.1	26.0	B	5.5	5.0/5.8
50	35/37.6	16.1	30.9	B	-0.7	4.4/3.5
50	50/54.1	16.1	32.7	B	-3.4	4.3/1.8
50	65/70.5	16.1	30.9	B	-3.5	4.4/1.8
50	80/86.7	16.1	26.0	B	-3.6	5.0/1.7
50	95/102.7	16.1	18.0	B	-3.7	6.4/1.6
50	100/107.9	16.1	16.1	B	-3.8	6.9/1.6
50	5/5.3	16.1	18.8	E	16.7	12.3/13.5
50	20/21.3	16.1	26.0	E	0.0	9.9/10.5
50	35/37.6	16.1	30.9	E	-6.9	8.8/5.8
50	50/54.1	16.1	32.7	E	-9.9	8.4/3.2
50	65/70.5	16.1	30.9	E	-10.1	8.8/3.1
50	80/86.7	16.1	26.0	E	-10.1	9.9/3.0
50	95/102.7	16.1	18.0	E	-9.9	12.6/3.2
50	100/107.9	16.1	16.1	E	-9.9	13.6/3.2
50	5/5.3	16.1	18.8	K	11.4	25.4/27.8
50	20/21.3	16.1	26.0	K	-8.0	20.4/19.4
50	35/37.6	16.1	30.9	K	-16.5	18.2/11.5
50	50/54.1	16.1	32.7	K	-20.4	17.5/7.6
50	65/70.5	16.1	30.9	K	-21.1	18.2/6.9
50	80/86.7	16.1	26.0	K	-21.4	20.4/6.6
50	95/102.7	16.1	18.0	K	-21.0	26.1/7.0
50	100/107.9	16.1	16.1	K	-21.1	28.1/6.9

TABLE C.3

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION ANGLE
WITH A CONSTANT LOW DIRECT PATH ELEVATION ANGLE
(0.1% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	5/5.3	16.7	21.9	P	-17.4	74.8/83.3
0	15/16.0	16.7	32.7	P	-44.4	52.9/50.6
0	30/32.7	16.7	49.3	P	-66.5	38.4/28.5
0	40/44.1	16.7	60.8	P	-75.0	33.6/20.0
0	50/55.7	16.7	72.4	P	-79.3	31.0/15.7
0	60/67.4	16.7	84.1	P	-81.7	29.8/13.3
0	75/85.1	16.7	78.2	P	-84.2	30.2/10.8
0	85/96.8	16.7	66.5	P	-85.4	32.1/9.6
0	100/114.0	16.7	49.3	P	-86.6	38.4/8.4
0	115/130.6	16.7	32.7	P	-87.5	59.9/7.5
0	130/146.6	16.7	16.7	P	-87.8	95.0/7.2
0	5/5.3	16.7	21.9	N	2.5	37.3/45.4
0	30/32.7	16.7	49.3	N	-33.2	19.1/14.2
0	50/55.7	16.7	72.4	N	-40.8	15.4/6.6
0	75/85.1	16.7	78.2	N	-42.5	15.1/4.8
0	100/114.0	16.7	49.3	N	-43.2	19.1/4.1
0	130/146.6	16.7	16.7	N	-43.2	47.3/4.1
20	5/5.2	15.0	19.9	M	8.7	23.3/29.4
20	20/21.4	15.0	34.5	M	-13.6	14.4/16.1
20	35/38.1	15.0	48.7	M	-22.3	11.1/7.6
20	50/55.3	15.0	61.0	M	-25.8	9.6/4.1
20	70/78.5	15.0	65.9	M	-26.5	9.2/3.4
20	85/95.8	15.0	57.3	M	-26.7	9.9/3.1
20	100/112.8	15.0	44.1	M	-26.8	11.9/3.1
20	115/129.9	15.0	29.6	M	-26.8	16.4/3.1
20	130/145.0	15.0	15.0	M	-26.5	29.9/3.4
20	5/5.2	15.0	19.9	N	1.4	39.2/48.1
20	20/21.4	15.0	34.5	N	-27.2	24.4/23.2
20	35/38.1	15.0	48.7	N	-38.5	18.6/11.9
20	50/55.3	15.0	61.0	N	-43.4	16.1/7.0
20	70/78.5	15.0	65.9	N	-45.1	15.5/5.4
20	85/95.8	15.0	57.3	N	-45.7	16.7/4.8
20	100/112.8	15.0	44.1	N	-46.0	20.0/4.4
20	115/129.9	15.0	29.6	N	-46.2	27.7/4.3
20	130/145.0	15.0	15.0	N	-45.8	50.4/4.6

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TABLE C.3 (Cont)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
20	5/5.2	15.0	19.9	E	21.6	5.4/6.9
20	20/21.4	15.0	34.5	E	6.3	3.3/6.0
20	35/38.1	15.0	48.7	E	0.4	2.6/4.1
20	50/55.3	15.0	61.0	E	-1.8	2.2/2.9
20	70/78.5	15.0	65.9	E	-1.7	2.1/3.0
20	85/95.8	15.0	57.3	E	-1.9	2.3/2.7
20	100/112.8	15.0	44.1	E	-2.3	2.8/2.6
20	115/129.9	15.0	29.6	E	-2.3	3.8/2.6
20	130/145.6	15.0	15.0	E	-3.5	6.9/1.8
20	5/5.2	15.0	19.9	C	23.0	4.4/5.6
20	20/21.4	15.0	34.5	C	8.0	2.7/5.0
20	35/38.1	15.0	48.7	C	2.3	2.1/3.5
20	50/55.3	15.0	61.0	C	0.2	1.8/2.7
20	70/78.5	15.0	65.9	C	0.3	1.7/2.8
20	85/95.8	15.0	57.3	C	0.1	1.9/2.7
20	100/112.8	15.0	44.1	C	-0.4	2.2/2.4
20	115/129.9	15.0	29.6	C	-1.1	3.1/2.1
20	130/145.0	15.0	15.0	C	-1.9	5.6/1.6
30	5/5.2	14.7	19.1	K	16.4	11.0/13.8
30	18/19.2	14.7	30.3	K	-0.1	7.3/4.6
30	38/41.3	14.7	45.6	K	-8.8	5.3/4.6
30	50/54.9	14.7	52.2	K	-10.5	4.8/3.1
30	68/75.5	14.7	54.6	K	-10.6	4.6/3.0
30	83/92.6	14.7	48.7	K	-10.7	5.0/2.9
30	98/109.3	14.7	38.4	K	-10.9	6.0/2.7
30	113/125.6	14.7	26.0	K	-11.0	8.4/2.6
30	123/136.1	14.7	17.4	K	-10.9	12.0/2.7
37.5	5/5.3	15.0	18.8	D	20.9	5.9/7.2
37.5	20/21.3	15.0	29.9	D	5.5	3.9/6.2
37.5	35/37.8	15.0	39.3	D	-0.5	3.1/4.0
37.5	50/54.6	15.0	45.3	D	-2.9	2.8/2.6
37.5	65/71.6	15.0	46.2	D	-2.9	2.7/2.6
37.5	80/88.4	15.0	41.7	D	-3.0	3.0/2.4
37.5	95/104.9	15.0	33.2	D	-3.4	3.6/2.2
37.5	110/121.0	15.0	22.6	D	-3.8	5.0/1.9
37.5	120/131.4	15.0	15.0	D	-4.0	7.2/1.8

TABLE C.3 (Cont)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.3	16.1	18.8	B	30.0	1.2/1.4
50	20/21.3	16.1	26.0	B	15.9	0.9/1.3
50	35/37.6	16.1	30.9	B	10.2	0.8/1.0
50	50/54.1	16.1	32.7	B	7.8	0.7/0.7
50	65/70.5	16.1	30.9	B	7.6	0.8/0.7
50	80/86.7	16.1	26.0	B	7.1	0.9/0.6
50	95/102.7	16.1	18.0	B	6.0	1.3/0.4
50	100/107.9	16.1	16.1	B	5.7	1.4/0.4
50	5/5.3	16.1	18.8	E	25.6	2.7/3.1
50	20/21.3	16.1	26.0	E	11.0	2.0/2.7
50	35/37.6	16.1	30.9	E	5.3	1.7/1.9
50	50/54.1	16.1	32.7	E	2.8	1.6/1.2
50	65/70.5	16.1	30.9	E	2.7	1.7/1.2
50	80/86.7	16.1	26.0	E	2.3	2.0/1.1
50	95/102.7	16.1	18.0	E	1.6	2.8/0.8
50	100/107.9	16.1	16.1	E	1.5	3.1/0.7
50	5/5.3	16.1	18.8	K	21.0	5.8/6.7
50	20/21.3	16.1	26.0	K	5.6	4.3/5.6
50	35/37.6	16.1	30.9	K	-0.6	3.7/3.3
50	50/54.1	16.1	32.7	K	-3.1	3.5/1.9
50	65/70.5	16.1	30.9	K	-3.1	3.7/1.9
50	80/86.7	16.1	26.0	K	-3.2	4.3/1.8
50	95/102.7	16.1	18.0	K	-3.0	6.0/1.9
50	100/107.9	16.1	16.1	K	-2.8	6.7/2.1

TABLE C.4

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION ANGLE
WITH A CONSTANT LOW DIRECT PATH ELEVATION ANGLE
(1.0% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	5/5.3	16.7	21.9	P	15.6	11.3/14.6
0	15/16.0	16.7	32.7	P	1.7	7.8/12.4
0	30/32.7	16.7	49.3	P	-7.0	5.6/6.9
0	40/44.1	16.7	60.8	P	-10.4	4.8/3.9
0	50/55.7	16.7	72.4	P	-11.2	4.4/3.1
0	60/67.4	16.7	84.1	P	-11.2	4.2/3.1
0	75/85.1	16.7	78.2	P	-11.2	4.3/3.1
0	85/96.8	16.7	66.5	P	-11.2	4.6/3.1
0	100/114.0	16.7	49.3	P	-11.2	5.6/3.2
0	115/130.6	16.7	32.7	P	-10.6	7.8/3.7
0	130/146.6	16.7	16.7	P	-7.4	14.7/6.5
0	5/5.3	16.7	21.9	N	22.9	4.2/5.5
0	30/32.7	16.7	49.3	N	4.1	2.1/4.1
0	50/55.7	16.7	72.4	N	0.6	1.6/2.7
0	75/85.1	16.7	78.2	N	1.4	1.6/2.7
0	100/114.0	16.7	49.3	N	0.0	2.1/2.5
0	130/146.6	16.7	16.7	N	-1.0	5.5/1.9
20	5/5.2	15.0	19.9	M	24.5	3.4/4.5
20	20/21.4	15.0	34.5	M	9.8	2.1/4.1
20	35/38.1	15.0	48.7	M	4.3	1.5/3.2
20	50/55.3	15.0	61.0	M	2.3	1.3/2.6
20	70/78.5	15.0	65.9	M	2.4	1.3/2.6
20	85/95.8	15.0	57.3	M	2.2	1.4/2.5
20	100/112.8	15.0	44.1	M	1.6	1.7/2.3
20	115/129.9	15.0	29.6	M	0.8	2.4/2.0
20	130/145.0	15.0	15.0	M	0.2	4.5/1.6
20	5/5.2	15.0	19.9	N	22.8	4.4/5.8
20	20/21.4	15.0	34.5	N	7.8	2.6/5.1
20	35/38.1	15.0	48.7	N	2.1	2.0/3.8
20	50/55.3	15.0	61.0	N	0.0	1.7/2.9
20	70/78.5	15.0	65.9	N	0.1	1.6/2.9
20	85/95.8	15.0	57.3	N	-0.1	1.8/2.8
20	100/112.8	15.0	44.1	N	-0.5	2.1/2.6
20	115/129.9	15.0	29.6	N	-1.1	3.0/2.3
20	130/145.0	15.0	15.0	N	-1.2	5.8/2.2

TABLE C.4 (Cont.)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
20	5/5.2	15.0	19.9	E	33.7	0.7/0.9
20	20/21.4	15.0	34.5	E	19.9	0.4/0.9
20	35/38.1	15.0	48.7	E	15.0	0.3/0.8
20	50/55.3	15.0	61.0	E	13.2	0.3/0.8
20	70/78.5	15.0	65.9	E	13.4	0.3/0.8
20	85/95.8	15.0	57.3	E	13.0	0.3/0.7
20	100/112.8	15.0	44.1	E	10.9	0.3/0.6
20	115/129.9	15.0	29.6	E	10.9	0.5/0.6
20	130/145.0	15.0	15.0	E	8.6	0.9/0.4
30	5/5.2	14.7	19.1	K	29.9	1.4/1.8
30	18/19.2	14.7	30.3	K	16.9	0.9/1.7
30	38/41.3	14.7	45.6	K	10.0	0.6/1.4
30	50/54.9	14.7	52.2	K	8.8	0.6/1.3
30	68/75.5	14.7	54.6	K	8.9	0.6/1.3
30	83/92.6	14.7	48.7	K	8.6	0.6/1.2
30	98/109.3	14.7	38.4	K	7.9	0.7/1.1
30	113/125.6	14.7	26.0	K	6.7	1.0/0.9
30	123/136.1	14.7	17.4	K	5.5	1.5/0.7
37.5	5/5.3	15.0	18.8	D	28.5	1.6/2.0
37.5	20/21.3	15.0	29.9	D	14.5	1.0/1.9
37.5	35/37.8	15.0	39.3	D	8.6	0.8/1.5
37.5	50/54.6	15.0	45.3	D	6.2	0.7/1.5
37.5	65/71.6	15.0	46.2	D	6.3	0.7/1.5
37.5	80/88.4	15.0	41.7	D	6.0	0.8/1.4
37.5	95/104.9	15.0	33.2	D	5.3	1.0/1.3
37.5	110/121.0	15.0	22.6	D	4.3	1.4/1.0
37.5	120/131.4	15.0	15.0	D	3.3	2.0/0.7

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TABLE C.4 (Cont.)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.3	16.1	18.8	B	39.1	0.2/0.2
50	20/21.3	16.1	26.0	B	24.8	0.1/0.2
50	35/37.6	16.1	30.9	B	19.8	0.1/0.2
50	50/54.1	16.1	32.7	B	17.4	0.1/0.2
50	65/70.5	16.1	30.9	B	17.2	0.1/0.2
50	80/86.7	16.1	26.0	B	16.5	0.1/0.1
50	95/102.7	16.1	18.0	B	15.1	0.2/0.1
50	100/107.9	16.1	16.1	B	14.6	0.2/0.1
50	5/5.3	16.1	18.8	K	34.9	0.4/0.5
50	20/21.3	16.1	26.0	K	20.6	0.3/0.5
50	35/37.6	16.1	30.9	K	15.5	0.3/0.4
50	50/54.1	16.1	32.7	K	13.1	0.3/0.4
50	65/70.5	16.1	30.9	K	12.9	0.3/0.3
50	80/86.7	16.1	26.0	K	12.3	0.3/0.3
50	95/102.7	16.1	18.0	K	10.9	0.5/0.2
50	100/107.9	16.1	16.1	K	10.5	0.5/0.1

of the average year. It should be noted that these results are applicable to a range of latitudes around the latitudes used in the calculations (e.g., about $\pm$ 5 degrees). In Table C.4, the results for rain zone B at a 50^{o} latitude are the same as would result for rain zone E, due to similar rain rates for 1.0 percent of the time. No results are given for rain zone C at 20^{o} latitude because there is negligible rain for 1.0 percent of the time in that zone.

Tables C.5, C.6, and C.7 are similar to tables C.2, C.3, and C.4, with the exception that a relatively high rather than low direct path elevation angle was used.

In Tables C.2 through C.7, values for the direct-to-indirect path interference power ratio that are less than about 20 dB indicate that rain scatter makes a relatively significant contribution to the total interference under the stated conditions. This can be seen to occur in the majority of cases. The low indirect path elevation angles in Tables C.2 through C.7 result in relatively high rain scatter interference components at large scattering angles. The margin values in Tables C.2 through C.4 indicate that for a constant earth station EIRP, the total interference does not generally decrease as much as the wanted path attenuation increases for numerous cases. In fact, the total interference almost equals that of the clear sky condition in many situations. The high direct path elevation angles in Tables C.5 through C.7 minimize the rain attenuations on those paths. However, the rain scatter contributions are nevertheless significant in comparison with the direct path interference in most cases.

Different Rain Conditions on the Direct and Indirect Paths

There is a non-zero probability that the rain conditions on the direct and indirect paths will differ. The worst-case with respect to interference occurs when the direct path interfering signal is subject to little or no attenuation while the rain scatter interference power component is high. Conversely, the lowest total interference would occur when there is high attenuation on the direct path and little or no interference from an indirect path. The probability of such occurrences can be deduced from diversity studies.

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TABLE C.5

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION ANGLE
WITH A CONSTANT HIGH DIRECT PATH ELEVATION ANGLE
(0.01% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	20/23.5	78.2	78.2	P	-10.3	74.5/63.8
0	25/29.4	78.2	72.4	P	-13.9	74.6/60.4
0	35/41.0	78.2	60.8	P	-18.5	77.7/55.9
0	45/52.4	78.2	49.3	P	-9.1	84.4/64.9
0	55/63.6	78.2	38.2	P	1.5	96.0/72.2
0	65/74.5	78.2	27.3	P	19.8	115.9/74.5
0	75/85.1	78.2	16.7	P	49.1	151.9/78.6
0	20/23.5	78.2	78.2	N	-6.8	46.3/38.7
0	25/29.4	78.2	72.4	N	-9.8	46.4/36.0
0	35/41.0	78.2	60.8	N	-13.9	48.3/32.2
0	45/52.4	78.2	49.3	N	-12.3	52.4/33.8
0	55/63.6	78.2	38.2	N	-6.4	59.7/39.0
0	65/74.5	78.2	27.3	N	3.7	72.1/44.8
0	75/85.1	78.2	16.7	N	22.3	94.4/46.3
20	5/5.2	66.5	65.9	M	13.2	30.0/29.7
20	10/11.[illegible]	66.5	63.9	M	4.6	30.2/28.6
20	20/23.2	66.5	57.3	M	-2.6	31.3/25.4
20	30/34.6	66.5	48.7	M	-6.2	33.5/22.8
20	40/45.8	66.5	39.3	M	-7.7	37.3/21.5
20	50/56.7	66.5	29.6	M	-2.6	43.6/25.7
20	60/67.4	66.5	19.9	M	6.1	54.5/29.2
20	5/5.2	66.5	65.9	N	10.8	47.6/47.2
20	10/11.6	66.5	63.9	N	2.2	48.0/45.4
20	20/23.2	66.5	57.3	N	-4.9	49.6/41.4
20	30/34.6	66.5	48.7	N	-8.1	53.1/38.8
20	40/45.8	66.5	39.3	N	-8.8	59.2/38.1
20	50/56.7	66.5	29.6	N	-1.4	69.2/44.2
20	60/67.4	66.5	19.9	N	12.4	86.5/47.7

TABLE C.5 (Cont)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES		RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
		DIRECT (degrees)	INDIRECT (degrees)			
20	5/5.2	66.5	65.9	E	19.4	9.2/9.1
20	10/11.6	66.5	63.9	E	10.7	9.2/8.8
20	20/23.2	66.5	57.3	E	3.3	9.6/7.5
20	30/34.6	66.5	48.7	E	-0.8	10.1/5.7
20	40/45.8	66.5	39.3	E	-3.5	11.4/4.1
20	50/56.7	66.5	29.6	E	-2.9	13.4/4.5
20	60/67.4	66.5	19.9	E	-0.9	16.7/5.7
20	5/5.2	66.5	65.9	C	21.7	6.0/5.9
20	10/11.6	66.5	63.9	C	13.0	6.0/5.7
20	20/23.2	66.5	57.3	C	5.5	6.2/5.9
20	30/34.6	66.5	48.7	C	1.2	6.7/3.5
20	40/45.8	66.5	39.3	C	-1.7	7.4/2.0
20	50/56.7	66.5	29.6	C	-1.7	8.7/2.1
20	60/67.4	66.5	19.9	C	-0.7	10.8/2.6
30	5/5.7	55.0	56.4	K	14.4	18.8/18.9
30	10/11.4	55.0	53.3	K	7.2	19.3/18.2
30	20/22.8	55.0	48.7	K	0.0	20.1/16.0
30	30/34.1	55.0	42.2	K	-3.8	21.6/13.7
30	40/45.2	55.0	34.4	K	-5.8	24.2/12.2
30	50/56.0	55.0	26.0	K	-3.4	28.4/13.9
30	60/66.6	55.0	17.4	K	1.9	35.7/16.7
37.5	5/5.6	46.5	46.2	D	19.6	7.6/7.5
37.5	15/16.9	46.5	43.8	D	7.7	7.8/6.9
37.5	25/28.1	46.5	39.3	D	2.3	8.3/5.5
37.5	35/39.1	46.5	33.3	D	-1.1	9.1/4.2
37.5	45/50.0	46.5	26.3	D	-2.8	10.6/3.2
37.5	55/60.7	46.5	18.8	D	-1.5	12.9/4.0

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TABLE C.5 (Cont)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.5	32.7	32.5	B	22.8	4.3/4.2
50	10/11.0	32.7	31.9	B	15.2	4.3/4.1
50	20/21.9	32.7	29.6	B	7.7	4.6/3.6
50	30/32.8	32.7	26.0	B	3.3	5.0/2.6
50	40/43.5	32.7	21.4	B	0.3	5.7/1.4
50	50/54.1	32.7	16.1	B	-0.6	6.9/1.0
50	5/5.5	32.7	32.5	E	19.2	8.5/8.4
50	10/11.0	32.7	31.9	E	11.7	8.6/8.2
50	20/21.9	32.7	29.6	E	4.4	9.0/7.1
50	30/32.8	32.7	26.0	E	0.3	9.9/5.6
50	40/43.5	32.7	21.4	E	-2.2	11.2/4.2
50	50/54.1	32.7	16.1	E	-2.4	13.6/4.1
50	5/5.5	32.7	32.5	K	15.4	17.6/17.4
50	10/11.0	32.7	31.9	K	8.0	17.8/16.8
50	20/21.9	32.7	29.6	K	0.9	18.7/14.9
50	30/32.8	32.7	26.0	K	-2.6	20.4/13.0
50	40/43.5	32.7	21.4	K	-4.3	23.3/11.8
50	50/54.1	32.7	16.1	K	-3.1	28.1/12.7

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TABLE C.6

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION ANGLE WITH A CONSTANT HIGH DIRECT PATH ELEVATION ANGLE (0.1% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	20/23.5	78.2	78.2	P	-4.0	30.2/24.8
0	25/29.4	78.2	72.4	P	-6.3	31.0/23.0
0	35/41.0	78.2	60.8	P	-9.0	33.6/20.7
0	45/52.4	78.2	49.3	P	-6.7	38.4/22.5
0	55/63.6	78.2	38.2	P	-0.3	46.5/26.7
0	65/74.5	78.2	27.3	P	12.0	61.7/29.8
0	75/85.1	78.2	16.7	P	39.8	95.0/30.0
0	20/23.5	78.2	78.2	N	0.1	15.1/12.1
0	25/29.4	78.2	72.4	N	-2.2	15.4/10.8
0	35/41.0	78.2	60.8	N	-5.3	16.7/8.6
0	45/52.4	78.2	49.3	N	-3.7	19.1/9.7
0	55/63.6	78.2	38.2	N	-0.9	23.2/11.5
0	65/74.5	78.2	27.3	N	4.6	30.7/13.7
0	75/85.1	78.2	16.7	N	17.4	47.3/14.9
20	5/5.2	66.5	65.9	M	19.5	9.2/9.1
20	10/11.6	66.5	63.9	M	10.8	9.3/8.8
20	20/23.2	66.5	57.3	M	3.5	9.9/7.5
20	30/34.6	66.5	48.2	M	-0.3	11.1/6.0
20	40/45.8	66.5	39.3	M	-2.6	13.0/4.6
20	50/56.7	66.5	29.6	M	-0.8	16.4/5.8
20	60/67.4	66.5	19.9	M	3.9	23.3/7.8
20	5/5.2	66.5	65.9	N	16.7	15.5/15.3
20	10/11.6	66.5	63.9	N	8.1	15.7/14.8
20	20/23.2	66.5	57.3	N	1.1	16.7/12.9
20	30/34.6	66.5	48.7	N	-2.3	18.6/11.1
20	40/45.8	66.5	39.3	N	-3.7	21.9/10.2
20	50/56.7	66.5	29.6	N	0.4	27.7/12.8
20	60/67.4	66.5	19.9	N	9.3	39.2/15.1

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TABLE C.6 (Cont)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
20	5/5.2	66.5	65.9	E	27.2	2.1/2.1
20	10/11.6	66.5	63.9	E	18.4	2.2/2.1
20	20/23.2	66.5	57.3	E	10.7	2.3/1.8
20	30/34.6	66.5	48.7	E	6.0	2.6/1.1
20	40/45.8	66.5	39.3	E	2.6	3.0/0.2
20	50/56.7	66.5	29.6	E	2.2	3.8/0.0
20	60/67.4	66.5	19.9	E	2.2	5.4/0.0
20	5/5.2	66.5	65.9	C	28.3	1.7/1.7
20	10/11.6	66.5	63.9	C	19.5	1.8/1.7
20	20/23.2	66.5	57.3	C	11.7	1.9/1.4
20	30/34.6	66.5	48.7	C	6.9	2.1/0.9
20	40/45.8	66.5	39.3	C	3.4	2.4/0.1
20	50/56.7	66.5	29.6	C	2.9	3.1/0.0
20	60/67.4	66.5	19.9	C	2.7	3.1/-0.1
30	5/5.7	55.0	56.4	K	22.0	4.6/4.6
30	10/11.4	55.0	53.3	K	14.5	4.7/4.5
30	20/22.8	55.0	48.7	K	7.0	5.0/3.8
30	30/34.1	55.0	42.2	K	2.6	5.6/2.7
30	40/45.2	55.0	34.4	K	-0.3	6.6/1.5
30	50/56.0	55.0	26.0	K	-0.2	8.4/1.6
30	60/66.6	55.0	17.4	K	1.5	12.0/2.4
37.5	5/5.6	46.5	46.2	D	25.0	2.7/2.7
37.5	15/16.9	46.5	43.8	D	12.9	2.7/2.5
37.5	25/28.1	46.5	39.3	D	7.2	3.1/2.0
37.5	35/39.1	46.5	33.3	D	3.3	3.6/1.1
37.5	45/50.0	46.5	26.3	D	1.2	4.4/0.3
37.5	55/60.7	46.5	18.8	D	1.3	5.9/0.3

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TABLE C.6 (Cont)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.5	32.7	32.5	B	31.9	0.7/0.7
50	10/11.0	32.7	31.9	B	24.3	0.7/0.7
50	20/21.9	32.7	29.6	B	16.4	0.8/0.6
50	30/32.8	32.7	26.0	B	11.3	0.9/0.4
50	40/43.5	32.7	21.4	B	7.3	1.1/0.0
50	50/54.1	32.7	16.1	B	6.3	1.4/-0.2
50	5/5.5	32.7	32.5	E	27.8	1.6/1.6
50	10/11.0	32.7	31.9	E	20.2	1.6/1.6
50	20/21.9	32.7	29.6	E	12.4	1.8/1.4
50	30/32.8	32.7	26.0	E	7.6	2.0/0.9
50	40/43.5	32.7	21.4	E	4.0	2.4/0.1
50	50/54.1	32.7	16.1	E	2.9	3.1/-0.2
50	5/5.5	32.7	32.5	K	23.6	3.5/3.5
50	10/11.0	32.7	31.9	K	16.1	3.6/3.4
50	20/21.9	32.7	29.6	K	8.5	3.8/2.9
50	30/32.8	32.7	26.0	K	4.0	4.3/2.1
50	40/43.5	32.7	21.4	K	0.9	5.1/0.9
50	50/54.1	32.7	16.1	K	0.5	6.7/0.7

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TABLE C.7

EFFECT OF VARYING EARTH STATION ANTENNA ELEVATION
ANGLE WITH A CONSTANT HIGH DIRECT PATH ELEVATION ANGLE
(1.0% of the average year)

LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
0	20/23.5	78.2	78.2	P	6.9	4.3/3.5
0	25/29.4	78.2	72.4	P	4.4	4.4/2.3
0	35/41.0	78.2	60.8	P	0.8	4.8/1.7
0	45/52.4	78.2	49.3	P	-0.6	5.6/1.0
0	55/63.6	78.2	38.2	P	-0.3	6.8/1.2
0	65/74.5	78.2	27.3	P	0.8	9.2/1.7
0	75/85.1	78.2	16.7	P	4.1	14.7/2.9
0	20/23.5	78.2	78.2	N	12.0	1.6/1.3
0	25/29.4	78.2	72.4	N	9.4	1.6/1.1
0	35/41.0	78.2	60.8	N	5.4	1.8/0.5
0	45/52.4	78.2	49.3	N	3.9	2.1/0.1
0	55/63.6	78.2	38.2	N	3.4	3.4/0.0
0	65/74.5	78.2	27.3	N	3.0	3.4/-0.1
0	75/85.1	78.2	16.7	N	3.0	5.5/-0.2
20	5/5.2	66.5	65.9	M	29.8	1.3/1.3
20	10/11.6	66.5	63.9	M	21.0	1.3/1.2
20	20/23.2	66.5	57.3	M	13.2	1.4/1.1
20	30/34.6	66.5	48.2	M	8.3	1.6/0.7
20	40/45.8	66.5	39.3	M	4.6	1.8/0.0
20	50/56.7	66.5	29.6	M	4.2	2.4/-0.1
20	60/67.4	66.5	19.9	M	3.6	3.4/-0.3
20	5/5.2	66.5	65.9	N	28.5	1.6/1.6
20	5/11.6	66.5	63.9	N	19.7	1.7/1.6
20	20/23.2	66.5	57.3	N	11.9	1.8/1.4
20	30/34.6	66.5	48.2	N	7.1	2.0/0.9
20	40/45.8	66.5	39.3	N	3.6	2.4/0.0
20	50/56.7	66.5	29.6	N	3.1	3.0/-0.1
20	60/67.4	66.5	19.9	N	2.9	4.4/-0.2

TABLE C.7 (Cont.)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
20	5/5.2	66.5	65.9	E	27.4	0.3/2.0
20	10/11.6	66.5	63.9	E	18.7	0.3/1.9
20	20/23.2	66.5	57.3	E	11.0	0.3/1.7
20	30/34.6	66.5	48.7	E	-6.5	0.3/0.3
20	40/45.8	66.5	39.3	E	3.1	0.4/0.3
20	50/56.7	66.5	29.6	E	2.3	0.5/0.0
20	60/67.4	66.5	19.9	E	2.4	0.7/0.0
30	5/5.7	55.0	56.4	K	33.3	0.5/0.5
30	10/11.4	55.0	53.3	K	25.6	0.6/0.5
30	20/22.8	55.0	48.7	K	17.6	0.6/0.5
30	30/34.1	55.0	42.2	K	12.4	0.7/0.3
30	40/45.2	55.0	34.4	K	8.3	0.8/0.0
30	50/56.0	55.0	26.0	K	7.9	1.0/-0.1
30	60/66.6	55.0	17.4	K	6.7	1.5/-0.3
37.5	5/5.6	46.5	46.2	D	31.8	0.7/0.7
37.5	15/16.9	46.5	43.8	D	19.5	0.8/0.7
37.5	25/28.1	46.5	39.3	D	13.4	0.8/0.5
37.5	35/39.1	46.5	33.3	D	9.0	0.9/0.2
37.5	45/50.0	46.5	26.3	D	7.0	1.2/-0.1
37.5	55/60.7	46.5	18.8	D	6.0	1.6/-0.3

TABLE C.7 (Cont.)

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LATITUDE (degrees)	GEO./TOPO. SAT. SEP. (degrees)	ELEVATION ANGLES DIRECT (degrees)	ELEVATION ANGLES INDIRECT (degrees)	RAIN ZONE	$P_{RD}-P_{RI}$ (dB)	WANTED PATH RAIN ATTEN./ MARGIN (dB)
50	5/5.5	32.7	32.5	B	40.9	0.1/0.1
50	10/11.0	32.7	31.9	B	33.2	0.1/0.1
50	20/21.9	32.7	29.6	B	25.1	0.1/0.1
50	30/32.8	32.7	26.0	B	19.6	0.1/0.1
50	40/43.5	32.7	21.4	B	16.9	0.2/0.0
50	50/54.1	32.7	16.1	B	14.7	0.2/0.0
50	5/5.5	32.7	32.5	K	36.8	0.3/0.3
50	10/11.0	32.7	31.9	K	29.1	0.3/0.3
50	20/21.9	32.7	29.6	K	21.0	0.3/0.2
50	30/32.8	32.7	26.0	K	15.7	0.3/0.2
50	40/43.5	32.7	21.4	K	12.7	0.4/0.0
50	50/54.1	32.7	16.1	K	11.7	0.5/0.0

It has been found that for the case of convergent terrestrial paths where the path lengths are smaller or comparable in size with the rain cell, the correlation coefficient of attenuations on the paths increases from 0.8 to 0.97 as the angle between paths decreases from 180 to 20 degrees[9]. This relates to a correlation between rain rates on earth-to-space paths, where the horizontal projection of slant path dimensions are smaller or comparable in size with the rain cell. This would be the case for even very small time percentages (e.g., 0.001), except for low elevation angle slant paths. If the probability of having rain of rate R on one path is 0.01, the correlation coefficient of 0.8 implies that rain of rate R would occur on both paths with a probability of about 0.985. Consequently, the occurrence of differing rain rates might happen for about 0.5 percent of the time that the rain is at rate R on one path in this example. There is certainly no need to consider differing rain rates on the direct and indirect paths for the time percentages of interest in this analysis, since rain of any rate might occur for no more than a few percent of the time during the worst-month.

CONCLUSIONS REGARDING RAIN SCATTER

Rain scatter interference between feeder links at 17.5 GHz appears to be neglegible. With geometries where the rain scatter interference may be high in relation to the direct path interference (large separations between satellites), the direct path interference is extremely low. For example, at a satellite separation of about 66°, the margin is -0.3 dB (Table C.7, rain zone K, 30° latitude). The clear sky C/I with 66° separation between satellites would be about 66.5 dB, as determined from the difference in desired signal and interference path antenna gains (56.5 dBi - (-10 dBi), for a 5.5 meter feeder link antenna). Rain on the interference path would be predicted to produce about a 0.3 dB decrease in the C/I with consideration of potential rain scatter effects, whereas the C/I would be expected to increase by about 1.5 dB (rain attenuation on interference path) when rain scatter is not considered. The difference in results is entirely negligible for such a high C/I.

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[9] CCIR, "Propagation Data Required for Line-of-Sight Radio-Relay Systems," Propagation in Non-Ionized Media, Report 338-2, Volume V, XIVth Plenary Assembly, Kyoto, Japan, 1978.

It is important to note that further study of rain scatter is required and the above results are provisional. A number of assumptions have been made in the analysis which could significantly affect the results.

APPENDIX D
DATA BASE

INTRODUCTION

The parameters required in the data base for earth-to-space propagation effects at 12 GHz and 17.5 GHz are established by the analytical methods of Appendices A, B and C. Two general categories of data are required: radiometeorological and physical/geometrical. The parameters in each of these categories are described in this section and the actual data is presented.

RADIOMETEOROLOGICAL PARAMETERS

The radiometeorological parameters required in the analysis are rain rate and height of the 0^{o} C isotherm, both of which are statistical, and an allowance for depolarization in the absence of rain. All three parameters are dependent on the rain climatic zone of the desired or interfering earth station. Figure D.1 is a map for determining the rain climatic zone and Table D.1 and Figure D.2 give parameter values as a function of the average-year time percentage[1]. It should be noted that when site-specific average-year data are available, these may be substituted for the generalized radiometeorological data in this data base for analytical purposes. The allowances for ice-induced depolarization are given in Appendix B.

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[1]CCIR, Radiometeorological Data, Report 563-1 (MOD F), Doc. 5/5049, Geneva, Switzerland, 10 September 1981.

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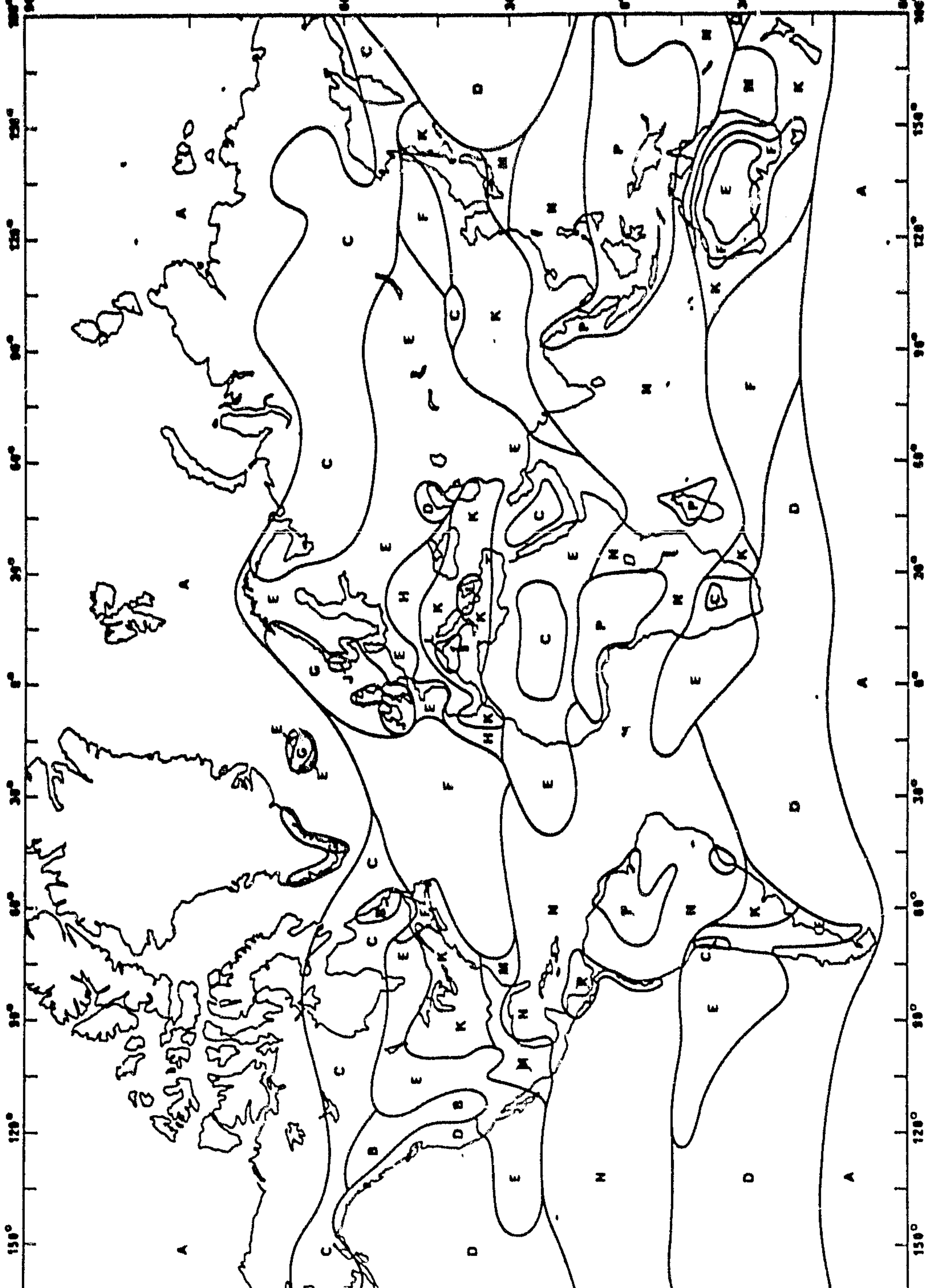

FIGURE D.1. RAIN CLIMATIC ZONES

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TABLE D.1

RAIN RATES FOR REGION 2 CLIMATIC ZONES AND AVERAGE-YEAR TIME PERCENTAGES*

(Rates in mm/h)

Rain Climatic Zone	Percentage of the Average Year			
	0.001	0.01	0.1	1.0
A	22	8	2	-
B	32	12	3	1
C	42	15	5	-
D	42	19	8	3
E	70	22	6	1
F	78	28	8	2
G	65	30	12	
K	100	42	12	2
M	120	63	22	4
N	180	95	35	5
P	250	145	65	12

*The significance of dash entries and blank entries is not clarified in the source document. A possible interpretation is that dashes mean that no significant rainfall was measured, whereas a blank means that no measured data was available.

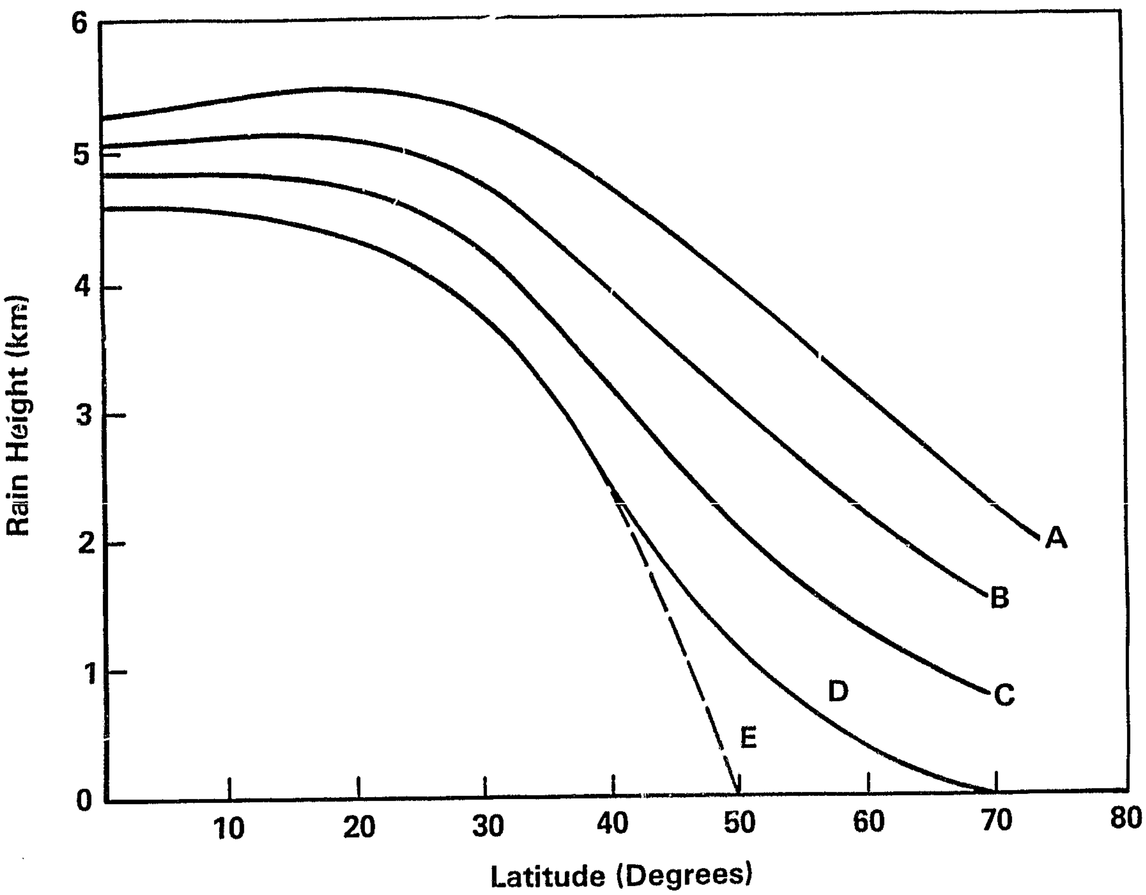

FIGURE D.2. HEIGHT OF THE 0°C ISOTHERM ABOVE MEAN SEA LEVEL

A – probability of occurrence of associated rain rate = 0.001%
B – probability of occurrence of associated rain rate = 0.01%
C – probability of occurrence of associated rain rate = 0.1%
D – probability of occurrence of associated rain rate = 1.0%
E – includes rain and snow occurrences

PHYSICAL/GEOMETRICAL PARAMETERS

The physical/geometrical parameters required in the analysis are earth station latitude and longitude, subsatellite point longitude and the height of the earth station antenna above mean sea level. Numerous possibilities exist for these parameters throughout Region 2, or even within a single Region 2 territory. Therefore, in the absence of specific data, the latitude and longitude data will be treated as variables in selecting scenarios for analysis. The scenarios that are used will reflect a representative cross section of possible parameter values. The earth station antenna will be assumed to be at mean sea level. Consequently, the results of the analyses will be useful only in relative terms. That is, the relative merits of various power control and polarization choices will be assessed.